Colour, Wavelength and Turbidity in the Light of Goethe’s Colour Studies

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Abstract
The polarity of light and dark in the treatment of the Newtonian spectrum and the inverse spectrum is studied further and the validity of heterogeneity of light and darkness in relation to Goethe’s views is examined. In order to clarify the reality of the “darkness rays”, the experimentum crucis is re-evaluated. It is shown that the commonly accepted analysis contains assumptions in the choice of the spectrum and background, which mask the inherent dynamic of the spectrum. The relation between colour and wavelength is re-examined with respect to the immutability and specific refrangibility of colour. It is then shown that both these properties are approximations that apply under the specific conditions that have later become standardized in spectroscopy, leading to a consensus regarding the relation of wavelength to colours of one particular spectrum. This consensus has resulted in the study of colour diverging into spectroscopy and colour physiology. As an alternative, the basis of the dichotomy postulated by Müller is studied, leading to the realization that the resolution of this dichotomy was begun by Goethe with the idea of turbidity. A further study shows that turbidity resolves the apparent incompatibility of light and dark.

Keywords Polarity · Colour theory · Experimentum crucis · Turbidity · Wavelength · Spectrum

1 Introduction
Recently, controversy has arisen with respect to the spectra produced by Newton and Goethe, as to whether or not Goethe’s inverse spectrum is as valid as Newton’s for the theory of colour (Lampert and Hampe 2018). Particularly with respect to Müller’s work (Müller 2015), some major themes under discussion have included: the interchangeability of light and dark in the experiments of Newton emphasized by Goethe in order to develop symmetric experiments (Müller 2015); the reality of darkness as a causative factor and the question of “heterogeneity of darkness” (Schreiber 2018); the relevance of polarity and enhancement as two factors studied in Goethe’s study of colour (Müller 2016a; Rang and Müller
In his paper (Müller 2018), Müller responded to the questions raised in the Special Issue of the Journal for General Philosophy of Science (Vol. 49(4)), and both his response as well as the earlier questions will form the basis for the current paper. It will be discussed here how the polarity of light and dark shows that they form a primary polarity when compared to other complementary-colour-polarities, and how interchanging light and dark leads to symmetric optical conditions. It will be shown that the concept of heterogeneity of darkness is an outcome of heterogeneity of light, and therefore it cannot be accepted without thoroughly verifying the heterogeneity of light. Since heterogeneity depends on immutability and specific refrangibility of colour, both these concepts are re-examined and shown to be compromised both theoretically and experimentally. In addition, the way the standardization of the colour spectrum compromises the recognition of colour polarity and the validity of non-spectral colours is described. This opens up a different path to resolving the question of the polarity of light and darkness: through Goethe’s concept of the turbid medium, but in the light of contemporary knowledge.

In Sect. 2, the interchangeability of light and dark will be discussed to point out some spectral features in addition to previous experimental results on the subject. The errors in attribution of the colour changes to the Bezold–Brücke effect alone, and the reasons for the choice of light and dark as the primary polarity will be described. In Sect. 3, the question of heterogeneity of the so-called darkness rays will be taken up by comparing the positions taken by Müller and Goethe. Section 4 will address the concepts of colour and wavelength by identifying the choices available in a prismatic spectrum for the colour pattern and for the linkage of a corresponding linear wavelength scale. The interrelationship of colour and wavelength established historically by Newton will be analysed in Sect. 5, with respect to specific refrangibility and immutability of colour. The standardization of the spectrum will be described in Sect. 6, and the resulting attribution of non-spectral colours to the physiology of the eye will be examined in Sect. 7. Finally, the importance of Goethe’s concept of the turbid medium (trübes Mittel) for resolving the dichotomy of light and dark, without utilizing either the heterogeneity of darkness or the underdetermination thesis, will be described in Sect. 8.

### 2 Symmetric Polarity of Light and Dark

With the arrangement of the prismatic spectrum, the regular Newtonian spectrum displays red, yellow, green, cyan and blue (also called dark blue or violet), while the inverse spectrum highlighted by Goethe, displays cyan, blue, magenta, red and yellow. In addition to the symmetries examined with this system through prior experiments (Holtsmark 1970; Rang and Grebe-Ellis 2018), there is one other feature regarding the spectrum colour sequences that is worth studying further. It must be noted that in case of the cadmium arc lamp, in the further extension when the screen is moved farther away, the colour sequence for the Newtonian spectrum undergoes two further transitions (See Fig. 3b in Rang and Grebe-Ellis 2009):

\[
\text{red–green–blue} \rightarrow \text{red–black–green–black–blue}
\]

A darkening appears between red and green, and between green and blue. Similarly, for the inverse spectrum:
What is the source of this darkening or brightening? In the Newtonian spectrum, cyan and yellow overlap to give green, and at a greater distance, cyan overlaps with red and yellow overlaps with blue. Since this is the behaviour in a dark background—as seen in the subtractive darkening towards green—these form complements that give black (subtractive colours). This is also indicated in Plate V of Zur Farbenlehre.\footnote{Please note that this plate is inaccurately coloured in several books by omitting the darkened band or brightened band in the spectrum. See Duck (2016, 37) for a more accurate plate.} Similarly, in the inverse spectrum, blue and red are initially adjacent to magenta. On extension, blue mingles with yellow and red overlaps with cyan, which form additive complements that give white. Therefore, the important point to be noted is that the disappearance through darkening in the Newtonian spectrum, and the corresponding brightening in the inverse spectrum, are also due to colour overlaps. The black and white match the respective backgrounds in which the spectrum is created. Once again, the symmetric polarity is consistently displayed, and the polarities complement one another in generating the full range of colours.

The issue of the disappearance of yellow and cyan has been clearly raised earlier by Ribe (1985). A similar disappearance of red and blue—or in other words, the appearance of brightening—has, as far as is known, not been pursued. Duck (1987; 2016) examines the disappearance of yellow and cyan—he refers to cyan as blue—and utilizes a specific effect: that of the change in hue due to reduction in brightness, leading to the extinction of yellow and cyan (the Bezold–Brücke effect). Not only does this approach mistake the relation between intensity of vision—as critiqued by Kidder (1989), Matthaei (1932), Currie (2010)—and its reduction in relation to colour overlaps, but the clear presence of yellow and cyan in the inverse spectrum even under dim conditions, which plainly contradicts the Bezold–Brücke effect, is not even addressed. Nor is there a clear reason provided for the disappearance of red and blue in the inverse spectrum. Duck’s approach therefore fails to argue for all the disappearances of colour, while seeming to support the Newtonian explanation with a physiological effect. This contradiction has also been pointed out by Zemplén (2001, footnote 174), even though he does reference the same concept in his later paper (Zemplén 2018, Sect. 3.1). A physiological reason to explain the behaviour of only selected colours and not the behaviour of the complementary colours in the complementary spectra is therefore inadequate. Instead, the phenomena must be valued for what they show: a polarity of obtaining black/darkening or white/brightening within the spectrum when the screen is extended to a distance.

In addition to the polarity of the disappearance of colours in complementary spectra, there is a second aspect of polarity related to the question: which choice of colours is best suited to express this polarity? Experiments have been done with variously coloured beams in different coloured backgrounds, by Nussbaumer (2008) as well as Rang and Müller (2009), where a wide variety of coloured bands develop, depending on the colour of the beam and of the background. This provides the impression that any spectrum can be chosen, in order to construct an alternative explanation of the spectrum phenomena. Lyre (2018, 528) considers this system thus:

This provides us with a first heuristic that it is, in principle, possible to produce infinitely many theories of ray optics. Pick out any colour C out of the colour wheel. Consider C-rays as fundamental and as consisting, in a systematic fashion, of ‘other’
colours (including black and white as components of C-rays). Hence, the domain of ray optics is underdetermined by an infinite class \( (C) = \{(C'), (C''), (C''')\ldots \} \) of empirically equivalent models (based on fundamental rays of colour \( C', C'', C'''\ldots \)).

While this approach of picking \( C \) and non-\( C \) as polar is possible in a theoretical sense, there are two problems with it. The first is that in several choices of \( C \), many of the colours are missing. See for instance plate XXVII in Nussbaumer (2008). This problem does not occur with the two spectra using white and black: the Newtonian spectrum and the inverse spectrum taken together. The second problem has to do with the concept of polarity: by its very nature, it denotes the extremes, or ‘poles’ of a series of physical observations. It must be noted that with respect to the brightness of the visible colours, white and black alone appear brighter and darker than all the other colours respectively, and so form a true polarity. In other words, while \( C \) and non-\( C \) can be complementary, white and black are true polars. Hence, for the study of colours, polarity must include white and black as its extremes, and this brings down the number of feasible theories from infinite \( (C', C'', C'''\ldots) \) back to two (black on white or white on black.) This makes the Newtonian spectrum and the inverse spectrum the two poles of experiences that any colour theory must come to terms with.

In addition, it must be noted that the polarity of edge colours seen in the case of a reflection of a prism-refracted beam from a mirror (Sällström 2010; Holtsmark 1970), as well as the polarity observed in the subjective prism spectrum vis-à-vis the objective (Duck 2016, 41), are important data points that must be systematically studied and included in the treatment of polarity. These, however, will not be elaborated in this paper.

3 Goethe and Heterogeneity of Light and Darkness

Müller (2016a) makes it clear that, contrary to Goethe, he does not wish to question the heterogeneity of light: “Objections to the heterogeneity of white light can be found throughout Goethe’s Farbenlehre. As I do not want to question the results of contemporary 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.” With this as the starting point, on the basis of the available evidence for the symmetric treatment of dark and light, Müller posits that darkness is also heterogeneous, since the phenomena are “prismatically equivalent”. As to whether this would be in line with what Goethe would have wanted to express, Müller is clear that it is not (Müller 2016a, 344; 2018) “He would have probably protested against the claim that Newton’s heterogeneity of white light is equally good a hypothesis as is its unorthodox alternative (the heterogeneity of darkness). He would have said that both hypotheses are equally bad.” However, Müller assures us that “Goethe did not have anything against the attempt to describe the world with the help of idealized, even abstract, theories,” basing himself on Goethe’s comment in Farbenlehre (Didactic) §159. Yet, Müller states the exact opposite earlier (Müller 2016a, 2018) “Goethe dreaded philosophical as much as scientific abstraction (see e.g. Goethe 1988, §716, §719–§721, §752).” It is clear that there is a problem with consistency in these statements, even at the initial level of clarifying which are Müller’s ideas and which are Goethe’s.

The theory of heterogeneity of darkness rests entirely on the theory of heterogeneity of light. It does not suffice to state simply that the heterogeneity of white light is an integral part of contemporary science, since that argument is not a scientific but a
contemporary historical one, and it would also remove the very foundation for examining the controversy between Goethe and Newton. There would be no need to examine the controversy, since the Newtonian theory of colours is already part of contemporary science. If the question is indeed taken up, it must be addressed in its entirety as far as possible. The question of composition of white light is not a trivial one (see Sabra 1981, 280; Shapiro 1980; Whittaker 1910, 17 note 1; Zemplén 2001). Hence, in this context it deserves a clarification, instead of a downplaying of the issue.

Secondly, as pointed out by Böhler (2018), the passage quoted by Müller (Leopoldina Ausgabe, Sect. I, Vol. 4, p. 5) does not indicate a free hand to theorize, since Goethe explicitly states (Goethe 1998, 84): “Search nothing beyond the phenomena, they themselves are the theory”. This objection is not addressed by Müller. A similar inconsistency of Goethe’s possible opinion on “dark rays” is pointed out by Zemplén (2018, footnote 6), showing that Goethe was a phenomenologist, and hence did not speculate in the form of hypotheses in order to explain phenomena, but rather experimented with different arrangements until the phenomena themselves revealed their lawfulness. It is hence quite obvious that Goethe held the theory of heterogeneity of both darkness and light to be unfounded.

Leaving aside the subject of Goethe’s opinion, the question of whether or not white light can be seen as a composition of “monochromatic rays” must be tackled independently, and it is important to do this by re-examining the experimental situation, without assuming the polychromaticity of white light as a given. It is in this context that the relationship of colour and wavelength must be re-evaluated.

4 Colour and Wavelength

In order to determine the relationship of colour and wavelength, the primary phenomenon that serves as a foundation is that of the colour spectrum. It is therefore important to examine two related questions regarding a spectrum:

1 What are the possibilities of colours in the spectrum?
2 What is called wavelength in terms of the spectrum displayed and the experimental setup?

These questions will be addressed below.

4.1 What are the Possibilities of Colours in the Spectrum?

For ease of reference, Goethe’s colour circle and the combinations of additive and subtractive colours are reproduced is shown in Fig. 1.

Obtaining a spectrum of colours in case of a prism involves positioning a screen on which the coloured beams can fall, whose precise position will now be addressed. Plate V from Farbenlehre is used here for reference (Duck 2016, 37).

In Fig. 2, the screen when placed at positions 1, 2, 3, and 4 gives four different cross sections of the spectrum. The most common choice for the spectrum cross section that is recognized as Newtonian is position 2, with the greatest diversity of colours. This particular position is also the foundation for one aspect of the theoretical assumption that white light is heterogeneous (the other will be covered in Sect. 7). Please note that at position 1, white is in the middle, and it can only be explained as being due to the “mixing” of different colours if position 2 is given the greater importance and relevance, and is used to explain the appearance of position 1, after the fact. This was precisely what was done by Newton, and is pointed out by Ribe (1985, 321): “More significantly, Newton’s explanation of the white image appears not when the original experiment is presented, but near the end of Book I, some 100 pages later. Newton thus reveals the complexity of the prismatic phenomena only after he has established his theory.” Greater weightage for position 2 cannot be theoretically assumed—it would have to be established, with a clear experimental justification.

Note that black is the ambient background colour, and the changes at a particular position can also be seen clearly by making the incoming beam narrower.

A similar development takes place in the inverse spectrum. Yellow and cyan are prominent here as they spread. There is, hence, a systematic development of the spectrum upon moving away from the light source. The result of the colour overlap is also opposite in the
two types of spectra: blue and yellow give a darkening in one case and a brightening in the other, as do red and cyan. In one case it is additive, and in the other case it is subtractive, a point that has been observed with respect to green and magenta previously (Currie 2010). If this overlap is not clearly recognized, it may appear that white light is “fully separated” into red, green and blue, and that yellow, magenta and cyan are also “separated out” in the other case. This fact has significant bearing on questions of “composition” or “decomposition”. The development of colours within these two spectra encompasses all the possible colours of the colour wheel.

4.2 What is called Wavelength in Terms of the Spectrum Displayed and the Experimental Setup?

It can be argued that the prerequisite for all modern spectroscopy is the assignment of wavelengths to colours. This requires the attachment of a numerical scale to the colour spectrum—a spectrum whose colours depend on the position of the screen just described. The question is: which position to choose?

All in all, there are at least eight distinct positions—Figs. 2 and 3—which are available for the placing of the screen, each of which gives a distinct combination of colours. Many other combinations of light beam and background colours are examined by Rang (2015). Even if the choice is to pick a position with the most number of colours, that still leaves position 2 for at least two distinct cases: black on white or white on black. Even if the choice is now to pick a position 2 of a white beam on a black background, there is still a degree of freedom in making this choice, since there is a spread of screen distances where this colour combination is seen. It is important to realize that before approaching the question of wavelength with an experimental setup for the determination of wavelength, a series of choices are already made. Since the historical choice has been the Newtonian rainbow position—approximately at 2—more than three centuries of repetition might make it appear that it is the only choice, followed by the attempts to explain the results of all the other choices using this one alone. However, one would still be picking up one particular colour pattern among a whole host of available ones.
In the history of spectroscopy, the first tool to be used extensively was the prism. One of the most skilled experimenters of the nineteenth century, Joseph von Fraunhofer, observed the spectrum using a small slit (15 arcsec wide, 36 arcmin high), with the prism being 24 feet away (Fraunhofer 1898, 4). Details of the prism are not given, but from the image he drew of his famous spectrum of the solar lines, it can be seen that he recorded the spectrum at a distance very close to position 2, such that the green is barely visible, and yellow and cyan are just beginning to merge (Fig. 4).

The prismatic spectrum was converted into a linear scale in many ad-hoc ways for a while, ranging from numbering, to letter codes, to comparison with distances between specified lines in a flame spectrum. Even Kirchoff and Bunsen, pioneers of prism spectroscopy with flames, recognized that numerical scales were arbitrary (Hentschel 2002, 52). In addition, each prism also had a slightly different spectrum depending on the material it was made from, complicating matters and showing the medium dependence of colour (Hentschel 2002, 55).

It became easier to assign numbers to colours when the colours alternated in a series of rings (Newton’s rings), and this was done by Thomas Young in 1821. He utilized the wave theory in order to establish a relation between the thickness of the air gap between a lens and a plane surface and the sequence of the colour ring. The ratio of these was given the name “wavelength”. This alternating behaviour is repeated in the case of a diffraction grating, and multiplied in various other configurations: Lloyd’s mirror, biprism interference, single slit diffraction, etc. Goethe had studied Newton’s rings, and their movement with change of separation, in his Farbenlehre (Goethe 1970, 116–119). In each one of these cases, the following observations hold:

- Dimensions of the slit/path differences must be in the micrometer range.
What appears at screen positions 1, 2, 3 etc. in case of a prism now occurs one beside the other at a single screen position, with the colour order reversed—blue is deviated less than red.

A similar dependence of colour-spreading on screen position is also present, but they are reproduced one beside the other.

The following pictures make this clear (Fig. 5).

In all three cases, for the white beam/circle, the red occurs away from the centre while the blue occurs towards the centre.

The development of gratings led to a clear linkage of the numerical scale to the spectrum, via wavelength, where wavelength was the ratio of the path difference to the order of the colour sequence, just as it was with Newton’s rings. Fraunhofer (1898) was the first to systematically utilize this rule to develop his wavelength calculations of the solar spectrum, while Ångström (1868) supplied the first standard set of wavelengths. In each case, the background was dark, with the slits at a considerable distance from the screen—e.g. 14 m for Fraunhofer. The reference wavelength tables were extended by Rowland’s concave gratings (Rowland 1902, part IV).

In the 20th century, interferometers were developed, which work on the same principle of creating a path difference and hence show the same features regarding the colour fringes (Fig. 6).

In both these cases, just as it is with a grating or with Newton’s rings, the white band has the red away from the centre while the blue is towards the centre. The basic phenomenon of the prism is repeated, with the introduction of rings and fringes when beam widths—or path differences—are restricted to the ~500 nm regime. What has not been adequately studied, as far as is known by the author, is what happens when light and dark are interchanged in the Newton’s rings setup such that the source of illumination is behind the flat surface instead of in front of it so that light hits the adjacent curved surfaces from the bottom, resulting in the bright and dark fringes interchanging, with the inverse spectrum being separated by bands of white. It can be done, for instance, by observing Newton’s rings with glass lens and plate held up to the sunlight. In this case, the “wavelength” calculation would be for the CMY inverse spectrum.

With prisms, gratings, and interferometers, the sequence pointed at from position 1 to position 4 is repeated. When a choice is made with respect to the background, and a
method is chosen, the spread of colour obtained is uniform i.e. with a dark background, one obtains the same Newtonian spectrum in different positions. Therefore, for the relationship of colour and wavelength, this spectrum is chosen by default as opposed to the inverse spectrum, for all the different methods.

Even after making such a choice, the next question is whether a specific colour can be assigned a specific wavelength. In other words, determining the immutability and refrangibility of a specific colour is a prerequisite to creating a one-to-one relation between wavelength and colour.

5 How are the Two: Wavelength and Colour—Interrelated?

Zemplén argues that Müller leaves out an essential part of Goethe’s colour studies by ignoring the transformations of the spectra: “The new colours spread further, and extinguish the two colours that gave birth to them: the yellow and the blue in the case of the white strip, the violet and the red in the case of the black strip. Bracketing the enhancement/advancement aspect is a lopsided interpretation of Goethe, who was an ‘extreme partisan’ of the evolutionary idea, as Darwin referred to him… his [Müller’s] mapping game is static” (Zemplén 2018, 541). Müller concedes that he has not dealt with this theme in depth, and adds: “Many scholars highlight this idea of enhancement because it fits well with Goethe’s morphological research in biology, which is widely considered a success… But although it may be interesting to look for connections between Goethe’s optical and biological research, this can distract from physical details. And while Goethe’s morphological research is important, it does not directly bear on his criticism of Newton.” (Müller 2018, 587)

This discussion is important to reference here since the concept of enhancement and advancement of colours is at the heart of the relation of colour to wavelength—a topic that serves as the very foundation of Müller’s thesis of heterogeneity of dark rays. If there was no specified relation between colours and wavelengths, there can be no reality attributed to individual “rays”, whether of light or of darkness. It does not make sense to set aside the discussion on enhancement because it “fits well” only with biological research—which is not relevant here—or because it can “distract from physical details”—which is untrue. On the contrary, the enhancement behaviour of colours provides the physical details necessary to evaluate the relation of colour and wavelength to each other.

The essential question is regarding the immutability of colour beams, both in the Newtonian and in the inverse spectrum. If a colour beam A can be transmitted through a varying series of media, and it can be shown that it still emerges only as colour A, then this homogeneity and immutability can be said to be established, and one can justifiably speak of a uniform “ray” of colour. In addition, if colour A refracts the same way each time with respect to the other colours, then its specific refrangibility can be said to be established. The experimentum crucis is the main experiment that is supposed to establish this, by filtering and purifying the incoming light into separate “primary rays”. There is considerable debate (Takuwa 2013) about whether Newton intended that the experiment should show diverse refrangibilities or immutability. As Lampert (2017, 9) puts it: “the presumption of the existence of light rays is a postulate rather than a statement within the theory.” However, the general Newtonian consensus today specifies a colour and a medium’s refractive
index for a particular wavelength. Both immutability and refrangibility are assumed to hold.

It is important to note the logical requirement that an experiment to establish immutability must not assume this very immutability in its explanations. Schaffer (1989) notes this tendency by showing how by defining a primary ray as one that could not be split further, Newton’s allies criticized those who had split the primary rays for their failure to produce primary rays—using the so-called ‘experimenter’s regress’. A similar presumption exists with the question of composition and decomposition: the very words imply heterogeneity, which can very easily become a hidden assumption of multiple immutable rays. Refrangibility as well as colour immutability must therefore be re-evaluated without assuming their existence. Since this is the crux of the issue, they will be examined here in more detail.

Refrangibility—in the experiment crucis (Newton 1979, 47, see Fig. 7), the key point that holds true throughout the apparatus is that the blue/violet end and the red end of the spectrum are at all times, mutually divergent.

Even when the two holes (G and g) line up horizontally such that the line joining their centres is perpendicular to the screens, there is still a chance that the direction of the colour beam is not perfectly horizontal due to the non-zero size of the holes. This means that the coloured parts of the spectrum entering the second prism abc on rotating prism ABC need not be precisely parallel to one another. Exaggerated depiction of this principle is shown in Fig. 8.

This configuration simply allows the divergence to continue to be effective even on the second prism abc, thus showing that the blue and red ends are separated in the final image. Goethe’s criticism of specific refrangibility (Duck 2016, no. 122–131) brings up precisely these questions, and as far as the author is aware, there has been no systematic
investigation of these objections on the basis of geometrical accuracy. It must be noted that a way of clearly examining the refrangibilities is not by turning prism ABC, which turns the entire spectrum and gives no control over the angle of incidence on the prism at the left, but to rotate the board d–e, the screen and the second prism abc as one unit around the point of divergence of the spectrum—depicted as centre in Fig. 9—while keeping prism ABC fixed. In this fashion, each coloured band can be sent through the hole g in board d–e at the same angle. While lenses have traditionally been used to improve the quality of this demonstration, rotation of part of the apparatus has not been done in the demonstration of the experimentum crucis so far.

A similar question arises centuries later even today with respect to refraction through a transparent glass slab. The sets of equations that are used to obtain dispersion in glass, such as Cauchy, Sellmeier, Hartman or Herzberger equations (Bass 1995) all assume a one-to-one correspondence between refractive index and wavelength. If the differentiated refrangibility for each colour was a physical fact, then on increasing the thickness of the slab, one must get a wider spectrum of a beam of light passing through it, as each deviation depends on the specific wavelength. This is not observed in reality. In fact, one must be able to get a wider dispersion of colour by using a thick slab than from using a prism, whose angle cannot increase past a point before leading to internal reflections. In Fig. 10, (a) is what is seen if a light beam enters from the top right, while we should expect (b) to be the display if colour-dependent refrangibility were to hold good.

Fig. 9  Ideal Scenario: Prism a–b–c, screen d–e and screen NM to be rotated about Centre

Fig. 10  a Passage of a light beam as seen, and b As expected due to specific colour refrangibility
One of the most prominent Newtonians, David Brewster—whose opinion of Goethe’s *Farbenlehre* was that it was “obscene and dangerous” (Burwick 1986, 34)—declared as a result of his researches with colour absorption that: “Difference of colour is therefore not a test of difference of refrangibility, and the conclusion deduced by Newton is no longer admissible as a general truth” (Brewster 1848, 72). If different colours were to display different refrangibilities by default, all light that passes through transparent media with parallel surfaces, whenever the image has a boundary of dark and light, ought to give a colour spectrum. Once again, this is not observable: a fact that was specifically pointed out by Goethe (Duck 2016, No. 77). In addition, the inverse spectrum with cyan, magenta and yellow, shows the order of deflection inverted once again, with cyan—the bluish colour—deflected the least and yellow—the reddish colour—deflected the most. Observationally, this is in stark contrast to the lesser refrangibility of yellow than cyan in the traditional Newtonian spectrum, showing once again that the refrangibility is dependent on the choice of background colour.

When looked at in conjunction with the various spectra possible with different colour combinations (Nussbaumer 2008), it becomes apparent that one particular colour can be present with different refrangibilities depending on the colour combination. Refrangibility is hence dictated by the geometry of refraction—such as the divergence of different parts of the spectrum—in conjunction with the colour combination, and is not specific to one colour. If one simply insists on one particular spectrum to define the refrangibility, such as picking the Newtonian spectrum with red being less deflected than blue, one particular colour—magenta—will find no place in the spectrum and will be labelled extra-spectral. The same is true if the inverse spectrum is picked—green becomes an extra-spectral colour.

Prior to assigning refrangibility to colour, these facts have to be taken into account, without which the assignment becomes compromised and dependent on a specially chosen set of conditions.

**Immutability of Colour**—with regard to this aspect, it is important to keep in mind that attempts at extracting a beam of a single colour from a spectrum have focused almost exclusively on the narrowness of this beam, brought about in a variety of ways: through narrowing the light aperture, using a converging lens or a convergent grating, increasing the slit-screen distance, etc. This focus was initiated by Newton himself, who asked that the “holes through which light was transmitted be made as small as possible … the best way … was to subject each ray to many successive refractions, not just two.” (Schaffer 1989, 83). A narrower beam experiences a lesser variation across its width while passing through a prism, and makes it more difficult to observe if it has changed colour at its sides.

A further contradiction exists in the use of a lens in this experiment. In the classic experiment (Newton 1979, 186), white light passed through a prism is spread in a spectrum, which is then passed through a lens and another prism in order to “reconstitute” white light in order to show its heterogeneity. By the same token, if a lens and prism are used in order to focus a particular beam of colour, it would tend to eliminate the coloured fringes that were usually obtained. However, focusing with a lens is said to prove that white light is heterogeneous, and at the same time prove that the coloured beam is homogeneous. The conclusion reached for the use of a lens with approximately one colour is the opposite of the conclusion reached for the use of a lens with white. In one case, the colours are said to constitute white light, in the other, the attempt is made to purify the ray. It may even be claimed, for instance, when yellow light gives green and orange at its extremities, that yellow is composed of green and orange, in the same way that white was to be composed of other colours. On the contrary, the logic is inverted here, and the attempt is made to change
the conditions of the experiment until the homogeneity of the coloured beam is rendered as uniform as possible, in order to prove the immutability of colours.

Goethe complained against the use of these narrow beams and stated (Duck 2016, No. 137) that colours will, even after a second refraction, acquire other colours at the borders. He even attempted to show this using his coloured beam experiments with water prisms (Goethe 1970, 146) (Fig. 11).

However, there is also another way of confirming whether or not colours are mutable: by making use of the relationship between the objective and the subjective spectrum. A white square on a black background, when looked at through a prism with its apex pointing downwards, will show a reddish-yellow border at the top, and a bluish border at the bottom. Upon looking at the image cast on a screen with white light cast from a square of the same shape, with the prism in the same position, the borders are inverted: blue border is at the top, the red is at the bottom. The image on the screen is the exact analogue of the subjective image seen through the eye, but displayed objectively and inverted. In one case the eye observes directly, in the other, the eye observes the image on the screen, and in both cases, the colours are the same. After establishing this for the black and white image, it can now be tested by using a prism to look at coloured bands, as in Nussbaumer’s work (2008). One can start with a colour in the centre, observe it through the prism, and observe the border colours. One of these border colours is then chosen, to make a patch on the same background, and the colours are observed again. For example, a yellow patch on a black background is observed, to get the corresponding border colours—in this case orange and green. In picking the lower border colour as the colour of the next image—green patch on black background—the border colours seem to “move” to reddish brown and navy blue. Upon picking navy blue as the next patch, one gets reddish-purple and dark violet-blue. Picking the orange end from the yellow patch gives red and dark green. Picking the top border or the bottom border for the colour of the next patch enables one to run through the entire Newtonian spectrum using yellow and cyan. Since red and dark blue are the limits of spectral colours on a black background, they form terminating points for these transformations. They do give dark-coloured borders, but these are very hard to see and distinguish from the surrounding black (Ribe 1985).
A similar series forms itself with the inverse spectrum in a white background, with pale yellow and cyan forming the limits of transformation. While the colours yellow and cyan in the Newtonian spectrum prove the most “mobile”, and easily give coloured borders that span the spectrum, and the same is true of red and blue in the inverse spectrum. Thus, when released from the requirements of being a narrow beam, when light of a certain colour is clearly produced as an extended beam and sent through the prism, one obtains a series of transformations of the colour in question. Taken as a whole, colour is mutable.

The most common objection to this may be a modified version of what Newton himself declared: “I believe [sic] all the colours proper to bodys [sic] are a little mixed” (Newton 2003). This belief, as stated, is a belief, and cannot be determined experimentally a priori (Blay 1983). The logic for this goes as follows: A spectrum is set up, and a small “ray” of colour A is obtained. When passed through the prism—or lens, or any other refracting element—again, if A is still A, then it is declared that the ray is immutable. If it gives border colours B and C, then A is said to be a “little mixed” with B and C in the first place, a posteriori. Repeated refractions are done, the slit is narrowed, prisms are replaced with better ones, and the beam focused. It then appears that A has very little B or C, and this is deemed satisfactory for all practical purposes. However, this bypasses the core issue at hand: the mutability of A into B and C. This objection has been noted since the early days of Newton’s theories (Schaffer 1989, 84). The means to address them have been focused on shrinking or narrowing the light beam in question, but not in expanding it, with the help of a convex mirror for example. Therefore, the immutability of colour has not been demonstrated, while mutability is the norm.

To summarize: specific refrangibility and immutability of colour, the prerequisites to establish the concept of a “homogeneous ray of colour”, are found to be untenable, logically and experimentally. A relationship also exists between Newton’s view of light in corpuscular form and his choice of heterogeneity of light. For example:

Blay shows that Newton began with an assumption of the corpuscular structure of light; that this assumption prompted an early commitment to the heterogeneity thesis; that this thesis is not proved by the so-called experimentum crucis using two prisms; and that this crucial experiment is in fact capable of an interpretation entirely consistent with the homogeneity of white light… Newton called them ‘experiments concluding directly & without any suspicion of doubt’. Blay shows how suspicious this claim always was. (Schaffer 1986, 124; Blay 1983; 1985)

Contrary to Blay’s interpretation that a priori conceptions direct the way science progresses, however, it can be stated that these a priori conceptions must always be treated as tentative, to be corrected and clarified based on the phenomena observed. Hentschel (2018) reiterates the importance of this corpuscular “mental model” with descriptions of Newton’s “globuli of light” in his notebooks. Darrigol (2002, 80) also states that “In the earliest optical experiments described in the philosophical notes of 1664, Newton used a prism as a velocity analyzer of the corpuscles of light.” A corpuscular carrier of light is the ideal carrier of a single colour as an immutable and pure object. According to Zemplén, “Newton’s ray-concept was intricately tied to a corpuscular assumption, and so is Müller’s alternative theory to Newton’s.” (Zemplén 2018, 538). This assumption of the “ray” has to be supported by the immutability of light and dark. Light is hence seen as a miniscule object, as a noun. However, in the grammar of colours, experiments show that colours are not as fixed as nouns but behave as verbs. Rather than seeing the transition of colour A to colour B and C as the presence of “unknown and unknowable” colours B and C hidden in the colour A—the noun approach—one can notice that the phenomena illustrate quite well...
that colour A becomes colour B and colour C—the verb approach. Lack of clarification of this essential feature of the language of colour as used by Newton and Goethe has been the cause of the misunderstanding that has persisted for a long time.

6 The Final Standardization of Colour

A related question that occurs is: If the mutability and lack of colour-specific refrangibility are true, what is the status of all the experimental results of spectroscopy in the three centuries since Newton, including those that gave rise to wave theory, quantum theory and so on? The important factor in this respect is that—as brought out in Sect. 4.2—not only was the spectrum usually taken at a certain distance in order to obtain the coloured Newtonian spectrum, but the background of all spectroscopy has been the dark chamber. Upon discovering the material dependence of prismatic spectra (called irrational), and noticing that the spectrum displayed through a grating was arrayed in a mathematically consistent fashion and was relatively independent of material considerations (rational), the grating was chosen as a better standard. See for instance the scale shown in Hentschel’s work between the prism and the grating, which shows the reason for this choice (Hentschel 2002, 50, 56) (Fig. 12).

It was this aspect of mathematical formulation, coupled with the ready availability of spectra of the sun and the chemical elements with reference lines, that enabled modern spectroscopy to arise. It must be noted that this material independence of diffraction gratings was still only an approximation. Marat (Conner 2012) had already studied diffraction in the shadows of different substances, and even later, Wood (1902) identified material-dependent features of a diffraction grating that later led to an entire field of physics of surface plasmon-polaritons (Maystre 2012; Arbabi et al. 2017).

Two key concepts—the ease of mathematization using reference spectra and the adaptation of a dark background—proved to be mutual standards agreed upon to pin the numbers to the diffraction orders using the concept of wavelength. It is this choice, more than anything else, that has given wavelength its relationship to colour with an apparent immutability. Müller had already described (Müller 2018, footnote 20) that “An important component of the solution is the wavelength \( \lambda \)… To measure it, Newton could have deposited a prototype prism in the Tower of London (analogously to the prototype metre in the Louvre): then he could have sent a homogenous ray of light through the prototype prism in a standardized geometrical setting and measured the result on a standardised screen; the outgoing angle could have been used as a measure for the refrangibility of the ray of light.”

Fig. 12 From Mapping the Spectrum (Hentschel), showing the variation in prismatic spectra, and the relation between a grating spectrum [Gitter] and that of a prism. The numbers indicate wavelength in nanometers
such a prototype prism was not deposited in the Tower of London, a Wavelength Commission did agree to an equivalent “prototype grating” by setting up the reference tables for solar spectral wavelengths in 1904 (Brand 1995, 52). However, a prototype background was also implicitly established, and black or darkness has been taken as the default background ever since Newton’s time.

It is only when the consensus created by “setting the standard” is clearly understood, that one can understand the real effect the Newtonian treatment of colour has had on modern science leading to the establishment of a universal standard for describing colours. Discrepancies in colour immutability are handled by increasing the resolving power, varying refractibility is handled by choosing a dark background and gratings, while white light heterogeneity does not have a direct bearing one way or another, and is still an unresolved question (Lombardi 1999). Hence, colour immutability, specific refrangibility and white light heterogeneity are not directly relevant to this standardization at all. The experimentum crucis was the first step in establishing one chosen standard for colour, much as the international departments of weights and measures have established a standard for other physical quantities. This is the basis for the current relation of colour to wavelength, when one says red has a wavelength of about 700 nm. It is also the basis for the inclusion of green and the exclusion of magenta in the currently accepted spectrum. Diagramatically, it can be shown this way (Fig. 13).

The dark triangle points to the primary colours in a dark background, while the white triangle points at the same in a white background. Since the intersection of a circle and a line is in one single point, this point is the “standard point” that relates to the standard wavelength scale. Naturally, an infinity of intersections between line and circle are possible for the various gradations of colours and backgrounds, but the polar opposite cases are the Newtonian RGB spectrum in the dark and the inverse CMY spectrum in brightness.

Numbers related to wavelengths are by consensus taken to be simple positive numbers, and are therefore not sufficient to incorporate the positive and negative nature of the polarity as shown by experiments. Also, once a wavelength standard has been fixed, there is at least one colour that does not “fit in”, and is at the opposite end of the colour circle. In the usual case, this is magenta, which is not assigned a wavelength. Where do these colours find a place in mathematization? The decision to affix the spectrum standard to the Newtonian spectrum has resulted in an implicit consequent decision: to relegate magenta to the physiology of the eye. It is to be noted that the reason one looks towards the physiology of the eye is not due to any particular scientific reasoning, but rather a result of choosing one.

![Fig. 13 One point of contact chosen between the linear spectrum and the colour circle](image-url)
arbitrary colour configuration for a numerical standard. If the inverse spectrum had been discovered first, then green would have been rendered equally “homeless” and attributed to the physiology of the eye and the dynamics of the nervous system. Where the Newtonian arbitrary standard stops, colour physiology and vision science take over. The theory of colours, however, need not be restricted to the black background alone, and as a result need not be split into the science of spectroscopy and the physiology of colour vision. The totality of the colour phenomena had to be tackled in any case, and since the choice of spectrum and its matematization has not been altered so far, one has been forced to tackle the shortcomings of the wavelength explanation using physiology, i.e. via a detour. Blay declares in a review (Blay 2014, 481) that:

Newtonian optics, by focusing on the question of the matematization of the phenomena of colour, profoundly transformed that which we call, since Newton, colours and the sensation of colour. A physiology and an analysis of the mental processes tied to the perception of colour thus become indispensible and new fields of research were brought into being.

It is therefore important to examine colour physiology and see if it provides the clue to an extended science of colours.

7 Colour Physiology and White Colour

It is admitted in standard psychology that “purple (magenta) is the only human non-spectral colour” (Cuthill et al. 2000, 175) or that “Purple, by contrast, is a non-spectral colour that cannot be generated by a single wavelength of light.” (Schwartz and Krantz 2018, 179). It is not noted that this property is a consequence of choosing a standard Newtonian spectrum. Occasionally, a text also inverts cause and effect thus: “Magenta is a non-spectral colour and thus was not included in Newton’s definition of fundamental colours,” (Rhyne 2017, 10) while also admitting that “The role that Goethe defined for Magenta is still applied today in modern colour systems.” By staying true to the nature of colour, and refraining from turning a circle into a line, all colours get their due.

As already mentioned, wavelengths are assigned positive numbers by definition, which means there are no “negative” wavelengths. However, the polarity of black and white is a
real factor in colour perception, and the positive–negative polarity has to be applied somehow in order to stay true to the phenomena. This polarity had to be accounted for in another way, and this way was opened up by studying the dynamics of the eye. An early pioneer of this work, inspired by Goethe, was Osann (O’Shea et al. 2017). On the same topic, a controversy flared up in the nineteenth century between Helmholtz and Hering (Howard 1999), where the three primary colours of the Newtonian spectrum—red, green blue—that Helmholtz supported were pitted against opponent-colour process advocated by Hering. The polarity was therefore incorporated as the active polarity expressed by the nervous system, and the current opinion is that: “We now know that both were right—Helmholtz at the level of receptors and Hering at the level of ganglion cells and beyond.” An image shown by Crone (1999, 232) shows the whole hierarchy of colour vision in this way (Fig. 14).

L, M and S denote long, medium and short wavelengths, or in other words, reddish, greenish and bluish colour receptors, while the colour-meters W-BL, Y-B, and G-R show the colour opponency. The meters indicate the polarity of white and black, with yellow and blue forming the first polarity of colours, just as Goethe stated (No. 201–202, Farbenlehre Didactic). Red and green can be attributed to the enhancement of the colours towards green and magenta, however magenta as such is still excluded since L, M, and S are still on a dark-background wavelength basis [even Land (1959) and Sällström (2017) use similar nomenclature]. The primacy of yellow as a perception is also highlighted through anatomy, where the red and green cones are 96% identical (Nathans et al. 1986), showing that yellow is more primary than either red or green. The reality of the negative polarity crops up repeatedly in vision science. Another example is that the colour matching in standard colourimetry once again uses “negative” primary colours (Smith and Pokorny 2003): “When the test light is a narrow spectral band, one of the primaries is always either negative; i.e. physically superimposed with the spectral test light to match the remaining two primaries, or zero.” The standard Wright-Guild data also incorporate this (Fairman et al. 1996). The phenomena of coloured shadows studied by Wilson and Brocklebank (1962) is another example of the reality of darkness as an optical factor (Wilson 1961).

The perception of white light is also addressed in modern studies of colour vision (Thompson 1995, 63): “Although Newton … claimed that perceived white is the most compounded of all colours… perceived white will result whenever both of the chromatic responses are neutrally balanced and that this can be accomplished in numerous ways with as few as two wavelengths of light.” This echoes the objections of Newton’s contemporaries such as Robert Hooke and Christian Huygens, where they indicated that it is possible to obtain white light with just two colours: blue and yellow (Shapiro 1973). The complementarity of blue–yellow, green–magenta and red–cyan show that obtaining white is indeed possible with just two colours. In case of additive colours, there are therefore several ways of getting white:

\[ W = R + G + B = Y + B = M + G = R + C. \]

In the Newtonian “composition” of colours into white, these overlaps come into play, such that they cancel the complementary colour effects to give the neutral white. The white that remains is dependent on the average brightness of the colours overlapped, and is therefore usually not as bright as the original white that gave rise to the colours in the first place. An increase in the number of complements would tend to average out the brightness even more, even though the white would still remain white. One cannot call this process a decomposition of white any more than one can call \( x \) and \( 1/x \), \( y \) and \( 1/y \), \( z \) and \( 1/z \) to be the decompositions of the number 1. Since any chosen pair of complementary colours in
the Goethean circle give white or black, one must treat the resulting colour in each case as a result of an overlap rather than as a colour “composed of” the original complementary colours.

Aspects of colour that were excluded at the outset by the decision about standardization of the spectrum show up again in the sciences of psychology and colour physiology. Even though all wavelengths are defined to be positive, the negative aspect appears in descriptions of neural physiology. This indicates that the study of colour, which was studied as a unity by Goethe, has been split into two parts due to this decision. A disconnected development of spectroscopy on the one hand and colour vision on the other is the necessary consequence of this decision, and it is important to see if there may be another way to incorporate this polarity directly into the understanding of colour behaviour.

8 Light, Dark and Turbidity

Müller bases his conclusions regarding the underdeterminacy of the Newtonian and its inverse spectra on the fundamental incompatibility between light and dark which lies at the basis of the two theoretical formulations (Müller 2015, 290f), or in other words, from the incompatibility between the terms “light ray” and “dark ray” which are non-reducible to each other.

However, as discussed earlier, the mutability of colours is a distinct and possible reality, and the very concept of “light ray” and “dark ray” as being fixed and incompatible elements is brought into question. This makes it possible for a light beam to darken—Newtonian spectrum—and a dark beam to lighten—inverse spectrum. This problem has not been sufficiently addressed, and Böhler (2018, 560) brings up a similar objection when Müller leaves aside the topic of the interplay of light and dark, by saying:

Quantitatively speaking, this means the “bracketing” and “falling-under-the-table” of almost 1000 of the 1400 pages in the first edition of 1810, approximately seventy percent, in other words. In terms of content it comprises—with the exception of the delegitimation of Newton—everything that Lyotard characterizes as Narrative Knowledge: the connectivity of various spheres of life and knowledge, as well as the historical, social, and individual legitimation of Goethe’s thought and investigations with respect to light, darkness, and colour.

In other words, more or less the entire understanding of Goethe’s theory hinges on the interplay of light and dark, and this interplay cannot be left aside. Rather than separating them, on a questionable basis, into two incompatible theories and establishing their underdeterminacy, it would seem more fruitful to see whether there is a way to alter our understanding such that the incompatibility turns into complimentary polarity.

Rang states the need for this (Rang 2015, 210): “Thus, if one wants to have a theory where symmetric or inverse states are also formulated symmetrically or inversely in theory, then neither the theory of ‘heterogeneity of light’ nor ‘heterogeneity of darkness’ is suitable. Instead, it seems promising to seek a combination.” Lyre (2018) has hinted at such a possibility with his science fiction story of the Möbius strip resolving the issue between two models of colour. Even Müller has indicated (Müller 2016b; 2018, 589) the way towards such a formulation, but has not followed it through: “Next, he [Goethe] uses numerous examples to illustrate the pattern he has in mind: in each case, there are two elements that form a polar opposition, e.g. attraction and repulsion … Goethe’s theorem
About the polarity of darkness and light] is at the core of the Farbenlehre.” Since the polarities in nature such as that between positive and negative poles of a magnet are already indicated by Goethe, it would make sense to incorporate both aspects, light and dark, in the same way that one has positive and negative charges as realities in electrical engineering, or acidic and basic behavior in chemistry. In fact, even the incorporation of positive and negative charges had to undergo a significant period of theoretical development (Nordmann 2003), and it is not surprising if a similar struggle occurs in incorporating the seemingly incompatible light and dark.

In order to properly evaluate Goethe’s terms light and dark, what is meant by them has to be more clearly understood. Strictly speaking, light as such is not visible or detectable without the presence of a material medium, therefore one cannot simply state that light is visible and darkness is not. Light exists without always becoming visible. If light as such is not necessarily made visible, it leads to the surprising result that light generated by the sun must also be called a colour, such as white, and not just as light. This has been explained in more detail by Steiner (2005, 210):

It is completely incorrect to believe that with light Goethe meant the concrete sunlight that is usually called ‘white light.’ Understanding of the Goethean colour theory is hindered only by the fact that one cannot free oneself from this picture of light and regards this sunlight, which is composed (zusammengesetzt) in such a complicated way, as the representative of light in itself.

Similarly, dark cannot mean something merely not activating the eye, since it is possible for something in the world to activate another sense, such as the sense of touch, or of heat or taste, even when not activating the eye. Active darkness is not simply the colour black, but is the presence of a material medium, or something that possesses mass:

The matter is therefore determined as the negation of light, or as a darkness… Matter, in contrast to this pure self, is the equivalent lack of self, or darkness. Its relation to light is that of sheer opposition. Consequently the one is positive and the other negative… Darkness vanishes before light; the dark body is the only corporeality to oppose it, and it now becomes visible. (Hegel 1970, 21).

This distinguishes the colours white and black, which form the limits of the eye, from light and dark: “White is the corporeal fixation of brightness, and is as yet achromatic; black is the materialization and specification of darkness; colour occurs between these two extremes.” (Hegel 1970, 142).

The gradations of the activity of light and dark therefore set up distinct regions. When the activity of light is predominant, the activity of its opposing darkness, or matter, must be a minimum. This occurs in substances that have mass and yet are not properly accessible to touch. These are gases and vapours. Hence, this domain, where light, and therefore the activity of the eye, predominates over darkness can be called Domain 1. Goethe called this the domain of physiological colours, and discussed the eye’s activity in the phenomena of after-images. Secondly, one has the domain of condensed matter: liquids and solids. In this domain, one extreme is when light’s activity is least hindered i.e. in transparency. The other extreme, after passing through all gradations of transparent coloured bodies, is when light’s activity is most hindered i.e. in opacity. At its limit, this opacity reaches white (No.147, Farbenlehre Didactic). This domain is Domain 2, also called physical colours. The third domain begins with white opacity, and after going through all the possible surface colours, has at its limit a pitch black object that absorbs all light: the so-called black-body. This is Domain 3, or chemical colours. It must be remarked here, that absolute
darkness is no more accessible to practical experimentation than absolute zero temperature or absolute vacuum.

If one wants to identify the midpoint of this “spectrum” of activity of light and dark that can serve to resolve the dichotomy, it could be sought in the middle of these domains, and more specifically in the middle of Domain 2, between perfect transparency and white opacity. This condition best suits what Goethe calls the turbid medium—trübes Mittel.

| Domain 1 | Domain 2 | Domain 3 |
|----------|----------|----------|
| Physiological colours | Physical colours | Chemical colours |
| Light through gas/vapours | Light through liquids/solids | Light on surface of liquids/solids |
| Darkness as blackness of space or as substance of gas/vapours | Darkness as substance of liquids/solids | Darkness as the opaque surface and substance of liquids/solids |
| Invisible—transparency | Transparency—white opacity | White opacity-invisible blackbody |
| Light | | Dark |
| Positive | Negative |

Hence, the behaviour of the turbid, semi-transparent or translucent medium is used by Goethe as a central “mechanism” for the development of colours. This concept, being far removed from the mathematized spectrum of Newton, and using a concept of active darkness that includes matter, has led to a lot of confusion in the literature. Sepper (1988) admits this confusion in his appendix on turbidity, but does not specify the reasons for the midway position of the turbid medium in Goethe’s treatment of colour, while Müller states that he finds the explanation “murky” (Müller 2015, 40). Proskauer (1986) tackles these ideas as well, but the different domains are not fully elaborated.

Once it is understood that Goethe was attempting to obtain a physical basis that incorporates both light and dark at the same time, including the concept of matter in that of darkness, the status of the turbid medium becomes better understood. Goethe himself struggled with the idea of turbidity for years, and appears to have reached a resolution only well after completing the Farbenlehre (Allert 2012), through the attribution of colour-genesis to turbidity itself. In keeping with the dynamic nature of this approach, turbidity also requires activity—light has to shine through a turbid medium, in order that it gives yellow or blue depending on a bright or a dark background. Activity of light and activity of dark are both capable of expression in the turbid medium. Lehrr states (Lehrs 1958, 317): “That it [air] was able to play this double role arose from its being on the one hand pervious to light, while yet possessing a certain substantial density. For a medium of such a nature Goethe coined the expression trübes Mittel.”

If the activity of light is termed positive and the activity of dark termed negative, what term can one use to describe the activity of turbidity? It is evidently not a neutral zero, as the positive and negative do not cancel out but retain their complementary role. In terms of numbers, if positive is denoted by positive numbers—such as the conventional wave-lengths—and negative is denoted by negative numbers—such as in colour opposition theories of vision science—a possible avenue for turbidity is offered in the use of imaginary numbers, which are neither positive nor negative. This has been mentioned previously by Steiner: “At this point you have to apply to the light effects a set of facts which today are only vaguely felt and not by any means explained, namely the relation between positive and negative numbers and imaginary numbers.” (Steiner 1988, 149). This concept will be
further elaborated in a separate work, and is only mentioned here as an example of the unique character of the turbid medium.

There is also a differentiation in the behavior of turbid media of different degrees. For instance, a very dilute turbidity, such as air from domain 1, requires an atmosphere-sized layer to evoke colour during darkening night and brightening day, while denser smoke can easily be seen as coloured with a bright or dark background. When using a milky white glass—Goethe often used silver-sulphate-incorporated glass—the turbidity has a greater amount of active darkness as compared to a clear transparent glass slab. Therefore, simply holding up the milky glass to the sunlight or even a white wall is sufficient to evoke colour. With a prism, one needs to look at a boundary of white and black through a prism in order to observe colours. The darkness has to be supplemented externally, and the dynamic overlap of white and black has to be accomplished through the angle of the prism, without which no colours are evoked—such as in a rectangular glass slab. This is at the root of the distinction between boundary modification and medium modification as discussed by Zemplén (2001), with the definition of turbidity incorporating both types of modification.

When light is manipulated within matter, as in LEDs or lasers, matter forms a dark background, making it easier to obtain the Newtonian spectral colours within such a system. In a diffraction grating with slits, the slits have to be reduced to a specific small micron-level-size—whose origin is not examined here—in order to allow the light and dark—the substance of the grating—to interact, generating a coloured spectrum. The grating is hence turbidity of a different nature, and the development of polariton theory (Maystre 2012; Arbabi et al. 2017) shows the validity of this idea. These are preliminary indications, and further research is necessary to establish the behavior of turbidity in polarization phenomena (entoptics), reflection, etc.

Thus we can understand how the incompatibility that Müller highlights between light and dark spectra can be resolved with the help of Goethe’s ideas of turbidity. Although Goethe was not able to develop it properly, it has nevertheless been possible to elaborate it based on the current knowledge of optics and colour sciences.

9 Summary

The polarity of light and dark requires a treatment of the Newtonian spectrum and the inverse spectrum as two polarities that utilize the natural polarities of white and black to give the full repertoire of colours. In the inverse spectrum, the concept of heterogeneity of darkness as used by Müller arises from a form of theorizing that is not encouraged by Goethe. The concept of “heterogeneous darkness rays” arises as a consequence of colour immutability and specific refrangibility, both of which are approximations that apply under the specific conditions that have later been standardized in spectroscopy. This has led to a consensus regarding the relation of wavelength to colours of one particular spectrum. Thus, there is no reason for assuming “heterogenous rays” to be an optical reality.

The attribution of only positive numbers to wavelength has resulted in the other half of the polarity—the negative half—being handled in the field of colour physiology and visual science colourimetry, with ideas of colour opponancy and “negative” primary colours. A resolution of the light–dark dichotomy that was begun by Goethe with the idea of turbidity was further elaborated, in order to show that turbidity resolves the incompatibility of light and dark in a way that is validated by current research without leading to
underdeterminacy. This resolution also points further to a different mathematical approach that can address the nature of turbidity and colour.

Even though some of the concepts explored in the paper might appear unfamiliar, and the numerical certainty of the Newtonian spectrum might appear well established, one should keep in mind that, in the words of Blay (2006, 10): “… even if it can appear to the modern physicist that this datum is almost an immediate and obvious experience, this is just a simple impression produced by three centuries of use and successive confirmations that in fact conceal its hypothetical and conjectural origin.” The approach to resolving the dichotomy of light and dark outlined here is a step towards a modern datum needed for grasping the totality of the behaviour of colours.

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