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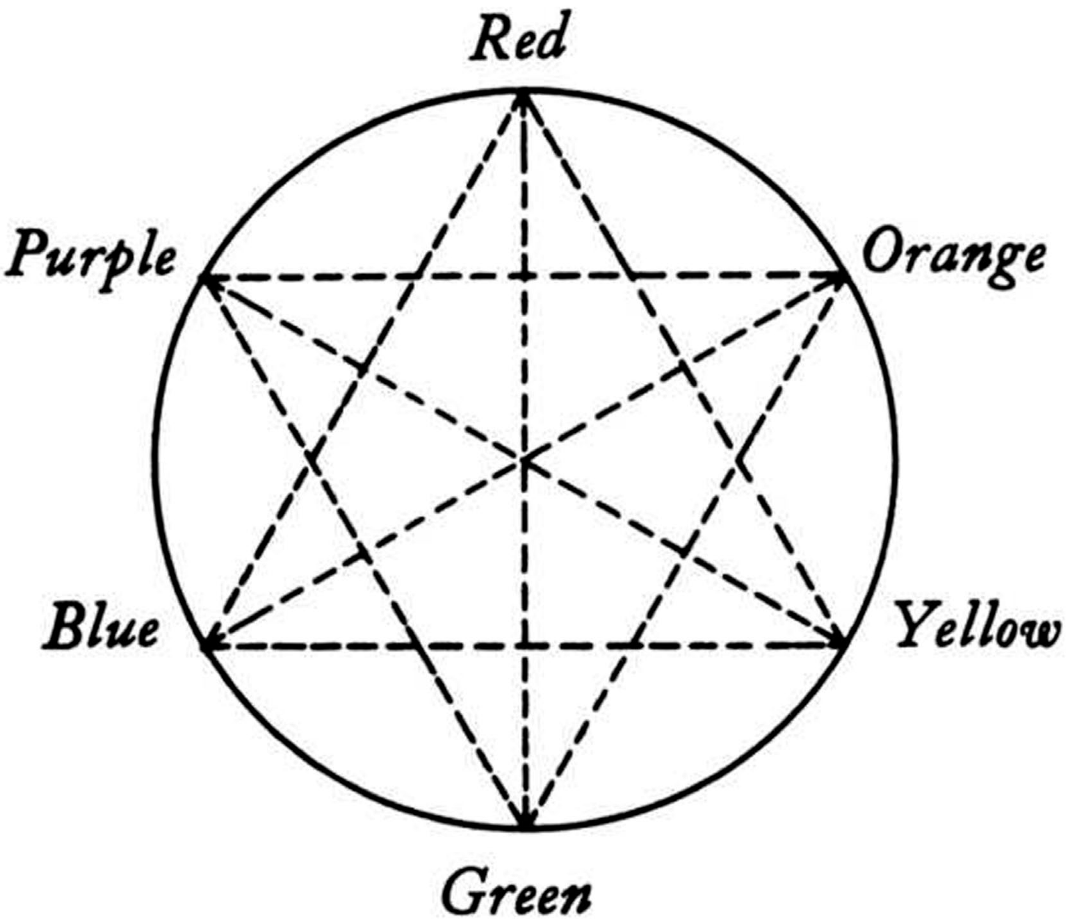

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Goethe's theory of colors between the ancient philosophy, middle ages occultism and modern science

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Abstract: Goethe's rejection of Newton's theory of colors is an interesting example of the vulnerability of the human mind—however brilliant it might be—to fanaticism. After an analysis of Goethe's persistent fascination with magic and occultism, of his education, existential experiences, influences, and idiosyncrasies, the authors propose an original interpretation of his anti-Newtonian position. The relevance of Goethe's *Farbenlehre* to physics and physiology, from the perspective of modern science, is discussed in detail.

Subjects: Aristotle; Biophysics; Experimental Physics; Fine Art; Medical Physics; Ophthalmology; Philosophy of Art; Philosophy of Science; Presocratics

Keywords: ancient philosophy; Greek–Roman classicism; middle ages science; Newtonian science; occultism; pantheism; optics; theory of colors; primordial phenomenon (urphaeno men)

1. Introduction

Light is one of the most interesting components of the physical universe. The fact that the rest mass of a photon is zero gives light a sense of immateriality that fascinated mystics, of course a long time

Andrei Merticariu

ABOUT THE AUTHORS

Victor Barsan is a senior researcher in theoretical solid state physics. In the last years, he was involved in some interdisciplinary research, like optics (electromagnetism/quantum mechanics analogies), history of physics, educational physics, popular science. He also authored several books or papers in recent history, human rights, philosophy of culture.

Andrei Merticariu is a physiologist involved in retinal research and surgery, with original contributions in retinal tomography. His competences cover cornean tomography and topography, computer-based perimetry, ocular tomography in optical coherence, etc. Andrei is a fellow of the European Society of Retina Specialists EURETINA.

In the present paper, the authors put together their competences in physics and physiology in order to provide a documented evaluation of Goethe's contributions in optics, colorimetry and human vision, from the perspective of modern science. Besides this article, the authors are involved in ongoing research of other aspects of Goethe's *Theory of Colors.*

PUBLIC INTEREST STATEMENT

Goethe was not only the author of *Faust* and of wonderful lyric poetry, but a passionate researcher in botany, anatomy, mineralogy, physics or physiology. He invested a huge effort, in the last 40 years of his life, studying light and colors—with the intention to demonstrate that Newton's results in optics were incorrect. The present paper analyzes the roots of Goethe's anti-Newtonian position: his fascination with magic and mystics, his pantheism, his obsession of not disturbing the "primordial phenomenon". This analysis is based on a large number of sources, pertaining to physics, physiology, philosophy, history of science—some of them used for the first time in this context. Even if Goethe's attempt to demolish the Newtonian physics is a complete failure, his effort is an interesting aspect of the transition from medieval to modern science. The valuable aspects of Goethe's investigations are carefully discussed.

before physicists had identified light quanta. The way light propagates, its wave and particle-like character, the crucial role it has played in the existence of life—all this has made the effort of to understand light a long, complex, sometimes incoherent and frequently polemical project. Among the most polemical controversies was the one that developed between the followers of Newton's theory, on the one hand, and Goethe and his supporters on the other. It is sometimes called "the Newton—Goethe polemics," although it never, of course, included a direct confrontation between the two namesake authors.

The starting point of the Goethe–Newton polemics is to be found in Goethe's *Theory of Colors* (*Zur Farbenlehre*). There Goethe disputes the correctness of Newton's discoveries concerning the decomposition of sunlight in spectral lines univocally characterized by a refractive index (nowadays we say, more simply: having a well-defined frequency) corresponding to rainbow colors. In its place Goethe adopts the standard Aristotelian theory, which claims that the colors represent a mixture between light and darkness.

The Goethe–Newton polemics are unusual, for several reasons. First of all, it represents the confrontation of a mainly humanistic genius (and, later on, of his epigones, admirers or followers) with the work of a genius of the natural sciences, the creator of modern physics and of calculus. All other polemics referring to light (corpuscle or wave, speed dependent or not on light source movement, etc.) have been confrontations of opinions among physicists.

Secondly, Goethe's criticism is surprisingly virulent, better suited to a merciless exchange of pamphlets than a scientific dispute. It is also surprising that Goethe, "in agreement [with physicists, our note] about the facts but in violent contradiction about their meaning" (von Helmholtz, 1898), remains inflexible in his anti- Newtonian stand, in spite of the attempts made by several German physicists to bring him back to a reasonable attitude.

Thirdly, the polemics are atypical in the extreme reactions simultaneously produced among physicists and humanists, Goethe's doctrine being fully rejected by the former, and praised, sometimes enthusiastically, by eminent personalities such as Hegel, Fichte, Schiller, and Schopenhauer. Goethe's *Theory of Colors* was so well received in some artistic milieus, that English painter J. M. W. Turner, one of the impressionists' forerunners, dedicated two paintings to that work as an explicit illustration of Goethe's understanding of colors.

The subject has been discussed in a large number of studies, spread over two centuries (see for instance Barris, 2002; Duck, 1987, 1988, 1997; Jaki, 1969; Jaspers, 2011; Ribe, 1985; Sepper, 2003; Theilmann & Grusche, 2013; Zajonc, 1976; Zemplen, 2001, 2006). Some researchers conclude that Goethe's aversion to Newtonian physics stems from his pantheistic beliefs (Wien or Duck, for instance), others—in his horror of abstraction (Heisenberg), or in his opting for a global approach in the study of nature (von Weizsaecker), or in his assumed agnosticism (Zemplen, 2001). Other explanations—from Goethe's incapacity to understand Newton's experiments to psychological speculations–are mentioned by Duck (references [4–7] in Duck, 1997).

Our main contributions to an understanding of Goethe's aversion to Newtonian physics consist in the following: (1) we point out the influence of medieval beliefs in magic and mystical experiences, as well as Goethe's idiosyncrasies and preconceptions on his researches in optics and on his scientific methodology. In this interpretation, we add new elements to those already identified by other researchers. In order to avoid the risk of subjectivity in the characterization of such a complex personality, we draw on the characterizations that the poet gives himself in his autobiographic works and in his correspondence.

As Goethe "has to approach colors, considered as physical phenomena" (von Goethe, 1840), we examine the evolution of the science of colors from Newton to the present. Our findings show that (2) Goethe deliberately ignores the achievements of his contemporaries, such as Tobias Mayer or

Lambert, and disregards the competent advice of respected scholars of his time, such as Lichtenberg, professor at the Göttingen University, or Boisserée, director of the Observatory of Munich—all of them followers, of course, of Newtonian physics. This finding allows us to situate Goethe's results properly in his own time as a researcher in the science of colors. We, furthermore, analyze the relevance of Goethe's scientific results as presented in his works on light and colors from the perspective of modern physiology and physics. While his enuring contributions to optics are modest, it is interesting to see (3) the way that some of his intuitions are compatible with the development of more recent science.

Let us describe now the structure of this paper. In Sections 2 and 3, we present briefly Newton's "new theory of light and colors," the critical reaction of several contemporary scholars, and its acceptance, at the beginning of the eighteenth century in the academic culture of the Continent. Sections 4 and 5 deal with light, color, human vision, and the light–sound analogy in order to lay the groundwork for our exposition of the science related to them. Section 6 discusses Goethe's involvement in the study of colors, Sections 7 and 8 the "didactic" and "polemic" parts of *Zur Farbenlehre*, respectively, and Section 9 the reception of these works. Section 10 presents a "spectral decomposition" of Goethe's personality as a first step toward the understanding of the sources of his anti-Newtonianism, discussed in Section 11. Section 12 provides an analysis of Goethe's contributions to the physiology of seeing, and Section 13, finally, an interpretation of his researches in optics from the perspective of modern physics.

2. Newton's theory of colors

Newton's contributions to the development of optics—amazing through their thoroughness and extent—are presented in two works published during his life, *The New Theory of Light and Colors* (Newton, 1993) and *Opticks* (Newton, 1730/1952), in a posthumous publication, "Courses of Opticks", as well as in his ample scientific correspondence. For our discussion, central is "The New Theory."

The letter where Newton announces to Oldenburg, the secretary of the Royal Society, his intention of introducing to the Society the results of his researches in optics (sent from Cambridge on 6 February 1672) describes that work as containing the most important discovery ever made on natural phenomena. This assessment is probably correct, if we limit ourselves to "laboratory physical phenomena," putting aside, for instance, the Copernican theory, i.e. the discovery of heliocentrism. It is not easy now to estimate correctly its importance, as the letter "connects two areas that have traditionally been considered as separate: the study of light and the system of colors." (Zemplen, 2001, p. 15). Let us see how Newton himself presents his discovery. In the letter it is entitled fully in *Philosophical Transactions of the Royal Society* 6, No. 80 (February 19, 1671/72), p. 3075:

> New Theory about Light and Colors: where Light is declared to be not Similar or Homogeneal, but consisting of difform rays, some of which are more refrangible than others: And Colors are affirm'd to be not Qualifications [=modifications, our note] of Light, deriv'd from Refractions of natural Bodies (as 'tis generally believed;) but Original and Connate properties, which in diverse rays are divers: Where several Observations and Experiments are alleged to prove the said Theory.

The work is written in a pleasant, colloquial, narrative style. Newton starts by telling how, after having procured the prism, he prepared his laboratory in order to study "the celebrated Phenomena of Colors. And in order thereto having darkening my chamber, and made a small hole in my window shuts, to let a convenient quantity of the sun light, I placed my Prisme at his entrance, that is might be thereby refracted to the opposite wall. It was at first a very pleasing divertissement, to view the vivid and intense colors produced by thereby …"

Further on the experiments are described; the exposition of scientific facts alternates with the presentation of his initial expectations, which sometimes differ from the result he obtains ("… an oblong form … which … I expected, to be circular"), hesitations, and abandoned intentions ("… I have sometime thought to make a Microscope"), autobiographical aspects ("Admist these thought I was forced to leave Cambridge by the plague, and it was more than two years before I proceeded further"). The conclusion of the experiments is summarized in 13 "propositions," in fact paragraphs. We shall fully quote the first one:

> As the Rays of light differ in degrees of Refrangibility, so they differ also in their disposition to exhibit this or that particular colour. Colours are not Qualifications of Light, derived from Refractions, or Reflexions of natural Bodies (as 'tis generally believed) but original and connate properties, which in divers Rays are divers. Some Rays are disposed to exhibit a red colour and no other, and so for the rest. Nor are there Rays proper and particular to the more eminent colours, but even to all their intermediate gradations.

This conclusion definitively eliminates the Aristotle's "theory," which dominated the explanation of colors for two millennia:

> It is conceivable that white and black should be juxtaposed in quantities so minute that [if a white and a black particle] either separately would be invisible, thought the joint product [of these particles, a white and a black one] would be visible… [it could be] neither white nor black; and, as it must have some color… this color must be … different from either." (Aristotle, *De anima*, 447a, quoted by Darrigol, 2012, p. 7)

This theory remained always vague; its variants used by Middle Ages scholars are carefully discussed by (Zemplen, 2006).

The experiments described by Newton in "The New Theory" are by no means the expression of a spontaneous inspiration. As the young Newton's Notebooks show, he studied in depth all the optics books available and concluded that Aristotle's theory is unsatisfactory. It is of course significant that Newton alluded to Aristotle's delimitation of Plato, in order to justify his own delimitation of Aristotle, when he wrote on his notebook the following motto: "Amicus Plato, amicus Aristoteles, sed magis amica veritas" (Zemplen, 2001).

"The New Theory" is considered a model of clarity and an exemplary illustration of the scientific method (Towne, 1993). Some 25 years ago, it was a part of a general education course at Amhrest College—called "Light"—one of the "Introduction to Liberal Studies" courses from which first-year students must choose. Some of the reactions of students with little or no background in physics sound like: "I didn't expect to understand anything, but I did." or: "The writing is simple, and the logic is clear."

If Newton is aware of the scientific value of "The New Theory"—as the letter to Oldenburg shows—he does not consider it, by any means, infallible. Let us quote the final sentences of his paper:

> This, I conceive, is enough for an Introduction to Experiments of this kind; which if any of the R. Society shall be so curious as to prosecute, I should be vary glad to be informed with what success: That, if any thing seem to be effective, or to thwart this relation, I may have the opportunity of giving further direction about it, or of acknowledging my errors, if I have committed any.

"The New Theory" has introduced in physics the concept of monochromatic light, which is fundamental for the entire optics; it made possible the spectroscopy, developed by Goethe's contemporary, Fraunhoffer, a century and a half latter; and spectroscopy provided one of the main investigative tools of both atomic and stellar physics of both the micro- and macrocosmos.

3. Contemporary critics of Newton's "New Theory"

3.1. Hooke and Huygens

Appended to Newton's paper, *Philosophical Transactions* publishes the following editorial comment:

> So far this very Learned and very Ingenious Letter; which having been by that Illustrious company, before whom it was read, with much applause committed to the consideration of some of their Fellows, well versed in this argument, the Reader may possibly in another Tract be informed of some report given in upon this discourse.

Indeed, between 1672 and 1676, 10 papers related to "The New Theory" were published in *Philosophical Transactions*, and they composed the first scientific dispute published in a scientific journal. The critics—some of them published immediately, some others remaining as scientific correspondence, and published later—are coming from two celebrated physicists—Hooke and Huygens—and from several less known scholars: Pardies, professor at the College Louis-le-Grand in Paris, and three Jesuits, Line, Gascoigne and Lucas ([10], I. iv).

Newton responds to Hooke after six months, so after a long gestation, and his ample analysis constitutes, among others, a pleading for the dual—corpuscular and wave—character of light. The replies to Huygens (the correspondence was usually mediated by the secretary of the Royal Society) are less elaborate, but in one of them Newton admits that he made a mistake when discussing the possibility of obtaining white light from mixing several colors (Mollon, 2003).

3.2. The Jesuits

Newton's attitude, however, to the criticisms of his other four contemporaries is completely different. The most interesting is Newton's polemics with Lucas. Displaying his versatility in subtle scholastic speculations, Lucas "reconstructs the logical structure of Newton's arguments" (Zemplen, 2001) and finds several weaknesses in Sir Isaac's theory. Newton considers these criticisms minor and is not willing to give a detailed response.

In a letter to Lucas, he writes: "instead of a multiple of things, try only the Experimentum Crucis. For it is not number of experiments, but weight to be regarded; and where one will do, what need of many?" (Zemplen, 2001). He seems ready to accept that his paper might have some imperfections, but they are related to "curiosities of little or no moment to understanding the Phaenomena of Nature" (Ref. 7 of Ribe, 1985).

Clearly, such disputes were, for Newton, a waste of time, and Lucas's insistencies are received with a certain irritation. "Pray trouble your self no further to reconcile me with truth but let us know your own mistakes" (Turnbull, 1960, p. 260). Several of Lucas's objections were probably due to his inability to remake Newton's experiments. Newton's final comment on Lucas's last letter (written to John Aubrey) is a refusal to continue this polemic: "I understand you have a letter from Mr. Lucas for me. Pray forbear to send me anything of that nature" (Turnbull, 1960, p. 263).

Newton's correspondence (1672–75) testifies to the tension and depression he experienced because of these polemics (mainly with Lucas), as he thought to withdraw from the Royal Society and to refrain from publishing his results (Vavilov, 1961). If he remained a fellow of the Royal Society, after Oldenburg's insistence, he persisted in his decision not to publish many of his results, which later on jeopardized the recognition of his priority in the creation of calculus. In any case, the effects of his disappointment with the severe and sometimes exaggerated criticism faced by the "New Theory" were very serious.

> Never again in his writings did Newton formulate his ideas as frankly and unprotected as he did in those 13 pages. In these later publications, in particular in his main works, Newton preferred the unassailable but rigid form of a mathematical treatment with definitions, axioms and propositions. Three reasons may have been responsible for this caution: first, Newton tried to avoid scientific arguments, which he hated but which he nevertheless saw himself confronted all time. [...] Second, Newton had a general and constantly growing distrust in argumentation of the Cartesian type. Third, his position on the interpretation of physical phenomena often remained open, because he himself could not make up his mind regarding a final opinion. (Roemer, 2009)

3.3. Newton on the Continent

Initially, Newton's theory was coolly received in France, as Edmé Mariotte reported in "De la nature des couleurs" (1682), describing an experiment that claimed to contradict it. Newton did not react at that time (he was deeply involved in other research, mainly connected to the *Principia*). Some 30 years later, he explained that Mariotte's result has to be expected in his theory, because the finite diameter of the sun and the light reflected from the clouds there implies an incomplete separation of simple colors by the first prism.

"The dilemmas began to disappear after the publication of Newton's treatise on *Opticks* in 1704. There, Newton described more refined techniques for purifying rays. The precision and abundance of the experiments contained in this treatise impressed continental readers. In France, large sections of the 1706 version of this book were read in public meetings of the Academy, in the year following its publication. Malebranche and de Mairan reported success in private repetitions of some of Newton's experiments. In Germany, Leibniz manifested interest in Newton's theory and his disciple Christian Wolff championed it in a textbook published in 1710. In a review that Wolff probably wrote for the *Acta eruditorum* of 1713, "the extremely sagacious Mr. Newton" was prayed to "condescend to devote attention to the problem raised about his theory by the highly ingenious Mariotte." Newton consequently asked the demonstrator of the Royal Society, John Theophilus Desaguliers, to perform publicly (improved versions of) his most important experiments, as well as to repeat Mariotte's. The second of these demonstrations occurred in 1715 in the presence of three French Academicians. By 1720, the doctrine that white light can be separated into simple, immutable colors with a specific index of refraction was broadly accepted" (Guerlac, 1981). A very interesting analysis of Newton's optics spreading on the Continent is given by Guerlac (1981).

So, Newtonian physics had finally been assimilated by the elite of French and German academic circles. This process lasted several decades and was based principally on scientific criteria. For instance, the tensions between German and English scientists due to the Leibniz–Newton dispute on priority in the creation of calculus did not hamper the recognition in Germany of Newton's achievement in physics.

4. Light, color, and human vision

In order to avoid confusion between "light" and "color," we shall outline here some basic facts concerning these concepts.

Light is the visible part of electromagnetic spectrum—the range of all possible wavelengths (or frequencies) of electromagnetic waves—i.e. of synchronized oscillations of electric and magnetic fields, perpendicular to each other and to the direction of propagation (see animation at https://en.wikipedia.org/wiki/Electromagnetic_radiation#/media/File:Electromagneticwave3Dfromside.gif).

The whole electromagnetic spectrum includes, in order of increasing frequency and decreasing wavelength: radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays. (See image of electromagnetic spectrum with visible light highlighted at https://en.wikipedia.org/wiki/Electromagnetic_radiation#/media/File:EM_spectrum.svg). The visible spectrum has wavelength from 400 nm (blue-violet) to 700 nm (red); green corresponds to about 550 nm (nm means nanometer; a millimeter contains one million of nanometers).

Color is the visual perceptual property deriving from the interaction of light with the receptors of human retina. So, light is a concept of physics, and color is a concept of physiology, psychology, and philosophy.

The science of color is sometimes also called chromatics or colorimetry. A fundamental theorem of colorimetry refers to the trichromacy of color mixture. This means that any color can be obtained as a certain mixture of three colors—for instance red, green, blue (RGB).

The trichromaticity of color mixture is due to the existence of just three types of color photoreceptor cone cells in the normal retina; each type of photoreceptor is sensitive to a range of the visible spectrum (essentially, of red, green, and blue); this is the basis of the trichromatic theory of color vision. A fourth type of photoreceptor cell, the rod, is also present in the retina; the rods are effective at very low light levels and are responsible for the "night vision."

Historically, the main difficulty in understanding colors is due to the fact that the trichromaticity of color vision was developed much later than the trichromaticity of color mixture. The consequence was that the trichromaticity of color mixture was considered to belong to optics, not to physiology. This is a categorical error, i.e. an error "with regard to the domain of knowledge within which a given observation is to be explained" (Mollon, 2003).

Let us mention some landmarks in understanding the trichromaticity of color mixtures. In his *Opticks* (1704), Newton introduces a "color circle"—"a forerunner of many other 'chromaticity diagrams', diagrams that show quantitatively the results of mixing specific colors" (Mollon, 2003). Before Newton, a small color atlas had been already published by Waller in 1686. The color print was invented in 1708 by Le Blon, where the trichromaticity of color mixing was clearly formulated for the first time.

Tobias Mayer, an astronomer from Göttingen, introduced a color triangle, with red, yellow, and blue at its corners. This chromaticity diagram may be refined by adding black and white, and a double pyramid is obtained in that way. Mayer's study, where the "boundary colors" are described half a century before Goethe, was published posthumously, in 1758, by G.C. Lichtenberg, professor of physics at the University of Göttingen. Lambert, the creator of photometry, realized that the chosen primary colors might have different coloring powers (*la gravité spécifique des couleurs*) and produced his own Farbenpyramide (1772).

The trichromaticity of human vision was discovered by two Londoners who never met each other, George Palmer and John Elliot, in several publications issued between 1777 and 1796. It was later clearly formulated by Thomas Young in 1801. Young attended the physics lectures of G. C. Lichtenberg at the University of Göttingen (1795/96) and knew the colorimetric researches of Tobias Mayer, as well as his descriptions of colored after-images, boundary colors, and simultaneous color contrast (Mollon, 2003).

This was the level of science of colors when Goethe started to work at his *Zur Farbenlehre.* Goethe ignored all the aforementioned contributors to the science of colors, and none of Goethe's works in this field was mentioned in an excellent study on the origins of modern color science (Mollon, 2003).

The "golden age" of the colorimetry and physiology of human vision (1850–1935), to borrow Mollon's expression, started with the researches of Helmholtz, Grassmann, and Maxwell (1852–55) and ended in the mid '30s of the 20th century. Helmholtz produced the first chromaticity diagram to have a modern form. Maxwell obtained the first empirical color-matching functions. Grassmann understood that colors are fully described by attributes of hue, brightness, and saturation. König and Dieterici, Helmholtz's disciples, gave the first realistic estimates of the sensitivity of the retinal receptors (1892).

In 1931, La Commission Internationale de l'Éclairage (CIE) adopted standard curves for a hypothetical standard observer. These curves can be used to specify how, to a given light—having a certain spectral power distribution (i.e. composed of monochromatic rays, each of them with a certain energy)—we can associate a set of three numbers, specifying a color univocally. With the impressive development of computers, it has become possible for anyone to visualize a color using the RGB values—see for instance the entries "colors" or "image processing" of the open access, user-friendly platform WolframAlpha. So, after three centuries, we have the confirmation of Newton's intuition: "I suppose the Science of Colours will be granted Mathematicall & as certain as any part of Opticks" (Zemplen, 2001, Note 33).

For the biochemists and biophysicists, working in the complicated political environment between the two world wars, the early 1930s brought the discovery of vitamin A in retina, of rhodopsin, and of all chromophores in the photosensitive cells of the eye responsible for human (and any mammalian) vision. These discoveries were rewarded with the Nobel Prize in Physiology and Medicine won by Wald, Hartline, and Granit in 1967.

5. Sound–light analogy

As the tricky analogy between light and sound produces difficulties in understanding colors, we shall try to describe some of its basic aspects.

Even if in contemporary times analogies are not credited among most productive methods of inquiry in physics (Barsan, 2012), the early days of science were quite different. "Men's labour … should be turned to the investigation and observation of the resemblances and analogies of things … for these it is which detect the unity of nature, and lay the foundation for the constitution of the sciences", said Francis Bacon (quoted in Black & Ankiewicz, 1985) almost one century before Newton.

Sir Isaac invoked a color–sound analogy while elaborating his color circle: the extension of sectors attributed to each color is done according to some proportions defined in acoustics. He extended the same analogy to the mechanism of seeing: the vibrations excited by light in the retina were directly transmitted to brain along the nerves (see Queries 12 and 14 of his *Opticks*, cited in Mollon, 2003, p. 9). It was a view almost universally accepted in the 18th century. The sound–light analogy, however, hampered the understanding of the trichromaticity of human vision. Since mechanical waves (sound) and electromagnetic waves (light) are very different, the sound–light analogy can be misleading. A consequence of the different ways in which sound and light act on human receptors is that hearing is an analytic sense (an educated ear can distinguish the "monochromatic" components of a sound), while seeing is in contrast synthetic (a similar operation cannot be performed by eye). An amusing illustration of the inappropriateness of sound–light analogy is the *clavecin oculaire* (Mollon, 2003).

The analogies are nevertheless credible and useful when different phenomena are described by exactly the same mathematical equations. So, as some electromagnetic equations (for instance, for the transverse electric field) are formally identical with the Schröedinger equation (for the wave function of a quantum particle), a precise analogy can be made between optical and quantum phenomena (Dragoman & Dragoman, 2004). We shall revert to this issue while discussing a maximalist interpretation of what Goethe called the *urphänomen* of colors—the light propagation in turbid media.

6. Goethe's involvement in the study of colors, "Beiträge zur Optik"

Goethe's interest in a systematic study of colors was awakened during his first journey in Italy (1786–88). "He noticed that artists were able to enunciate rules for virtually all the elements of painting and drawing, except color and coloring. The artists he associated with were unable to explain their practice to his satisfaction. A reference work also gave little useful information, so he began his own investigation. A friend painted pictures to test some of Goethe's ideas, but without any definite results. He also recorded observations in nature, but nothing coherent emerged from these occasional impressions" (Sepper, 2003, p. 23).

After his return to Weimar, Goethe decided to undertake a systematic study of colors: "Ultimately, I recognized that one has to approach colors, considered as physical phenomena, from the perspective of nature first at all, if one wants to gain something about them for the purpose of the art" (our emphasis, see Sepper, 2003, p. 24).

After having read "in some compendium or other customary chapter"—the content of these compendia will be discussed later on—Goethe decided to repeat the experiments described in those books. He prepared one room as *camera obscura* and borrowed a prism from a friend, but he did not find the time to start the research. When he was asked to give the prism back, Goethe decided to watch through it the room where he was at that moment—a normal room, not that one prepared as *camera obscura*—and what he saw did not match the descriptions given by the compendia. The conclusion struck him quickly and remained final: "I immediately said to myself, as if by instinct, that the Newtonian teaching is false."

Subsequently, Georg Christoph Lichtenberg, professor of physics at Göttingen (as already mentioned in Section 4, Thomas Young attended his lectures in 1795/96), explained to Goethe that what he had seen through the prism was exactly what Newton's theory predicts, if one uses it in an illuminated room, not in a *camera obscura*, but the poet's aversion to Newton remained unchanged (Jaki, 1969).

Goethe's obstinacy is surprising, the more so as the knowledge he had, when he started to challenge Newton, was very modest. It would be useless to say that he had never read a word of Newton's works. "At university, I had had physics like everyone else and had been shown experiments," says Goethe. After an effusive recollection of the courses on electricity given at Leipzig by Winckler—a name which did not endure in the history of physics—he also mentions that he could not remember any experiment devoted to the "Newtonian theory": since they used, as light source, the sun rays, "they were usually postponed until there is sunny weather, and they are shown out of the running sequence of the lectures" (Sepper, 2003, HA, 14, pp. 256–257).

Not being a position to challenge Newton's theory with the knowledge he had acquired during his university years, Goethe resorted to compendia, as just mentioned. The level of sophistication exhibited by those compendia is quite modest, without up-to-date results or theory, reflecting "the state of the basic teaching of natural philosophy to the best-educated young student of the era" (Sepper, 2003). For instance, Erxleben's compendium, consulted by Goethe, devotes about 15 lines to the description of refraction through prism and to *camera obscura*.

Goethe preparing to check Newton's experiments clearly suggests that he understood the discrepancy between his own knowledge and the task to be assumed. "Goethe declares himself hesitant to venture into an investigation that requires not only that one judge the validity of experiments that are 'complicated and hard to reproduce,' but also that one enter into an abstract theory whose 'applications cannot be judged without the most exact insight into higher mathematics" (Sepper, 2003). Being aware of these difficulties, Goethe considers that:

> my duty was to perform once again as exactly as possible the well-known experiments, to analyze, compare, and order them, through which effort I was able to invent new experiments and make their sequence more complete. (von Goethe, 1840)

Goethe's interest is mainly directed to the light spectrum dispersed by the prism, when the demarcation between a white and a black surface is seen, these surfaces having in general rectangular shapes. In this case, the spectrum appears to differ from that described by Newton in "The New Theory" because of some boundary effects, easily explained by Newtonian optics. Indeed, Newton had actually known this phenomenon (probably, he had even discovered it) and had presented it in his "Courses of Opticks," a work not known to Goethe. The poet erroneously considers it probable that he is the discoverer of boundary spectra and that their existence contradicts Newtonian theory. In opposition to Newton, from such experiments Goethe hoped to obtain arguments in favor of Aristotle's theory of light. He repeats and diversifies several well-known prismatic experiments, and his results, conclusions, and comments are published in a work of modest dimensions, "Beiträge zur Optik" (hereafter quoted as "BzO"), composed of two parts, issued in 1791 and 1792.

Although the polemic character of BzO is mild, it is clear that the book intends to prove Goethe's opinion scientifically "that the Newtonian teaching is false." The criticisms pointed at Newtonian theory in BzO have been analyzed by Sepper (2003), and synthesized in seven objections. Without recalling them here, we shall only mention that:

- The first four objections represent qualitative conclusions of Goethe's experiments, which are, according to Sepper, presented in opposition to Newtonian theory. Actually, they can be perfectly well explained within the frame of Newtonian optics. More than this, the Newtonian approach allows quantitative description of the respective phenomena.
- The fifth objection refers to the color wheel proposed by Newton. Goethe criticizes it because it contains only the spectral (rainbow) colors—but this was exactly Newton's intention, and the wheel has the advantage of making it possible for the eye to perceive the white colors if the wheel (with colored sectors appropriately gauged) is rapidly rotated. The dimension initially chosen by Newton for the respective sectors is based on a color–sound analogy, which had been proved as unsubstantiated, but the choice is not arbitrary, as Sepper states (Sepper, 2003, p. 84).
- The last two objections are irrelevant and will not be discussed here.

Therefore, as Sepper shows, BzO does not succeed in producing sound criticisms of Newton's theory.

In the BzO, Goethe avoids explicit opposition to Newton. His aversion toward the British scholar is nevertheless evident. For instance, he points out that during the 18th century important objections were raised against his theory and, though some were left unanswered, the powerful Newtonian school had repeatedly suppressed criticism and relegated the critics to oblivion.

What exactly does Goethe mean this? He avoids explicit explanation, as he will frustratingly often do when in criticisms against Newton. As we have seen, the objections raised by Mariotte were not suppressed in the way Goethe describes; they were solved in an utmost scientific manner. There is no indication that Goethe would have known the obstacles the Newton's optics had to overcome before being enforced in France and Germany, where Sir Isaac was accepted for purely scientific reasons. In fact, one cannot speak, in the eighteenth century, about a "strong Newtonian school," or about fighting criticism by any form of authoritarianism. Indeed, through such charges, Goethe's good faith becomes questionable.

An ironical comment addressed to the "profound man" (easily identifiable with Newton) is characteristic of Goethe's irrational attachment to color. Removing or attenuating the chromatic aberrations of optical instruments—one of Newton's concerns, and, in fact, of any researcher interested in the construction of high-quality optical instruments—is, for Goethe, an offense to colors: "color is a nuisance to be gotten rid for the sake of improving optical instruments, more than it is a subject for investigation on its own right".

It is not surprising that, containing no new physical result and including ironies and allusions inappropriate to a scientific text, BzO was received without enthusiasm; but that fact did not discourage Goethe. He records, lucidly, that the reviews show him "haughty condescendence …. They reported my effort in such a way as to help it to sink into oblivion forever" (Jaki, 1969). Goethe would have liked for BzO to set a direction to be followed by other researchers, as he declares in "Konfession", but in their absence he will continue the researches on his own.

The troubled times do not divert Goethe from studying colors. During the 1792–93 campaign against France, Goethe carries with him the four volumes of Gehler's *Physics Dictionary*. Asked by Prince Reuss, during the bombing of Verdun, what he is thinking about, Goethe "begun to speak with great animation of the doctrine of colors," according to his own confessions. Back to Weimar, after the end of the war, Goethe gets Newton's *Opticks*, and succeeds in going over the first part (out of the three of the book) and in reproducing some experiments. At the same time, he reads almost all the literature referring to colors he can procure, from the antiquity until his time. It is evident that Goethe's focus on the old works, not on the recent ones. It is also clear that Goethe could not understand the 2nd and 3rd parts of Newton's treatise, or, in any way, for instance, the description of the interference rings.

For the years 1794–97 there are no indications that Goethe studied colors; however, in 1796 he publishes versified epigrams against Newton and his school.

Excepting such interruptions, Goethe's researches on colors, subsequent to the publication of BvO, cover almost two decades, and come to a conclusion with the elaboration of three volumes of his *Theory of Colors* (1808–10). The first one contains the "didactic" part, "Outline of a Theory of Colors"; the second, the "polemical" one, "Exposure of Newton's theory"; the third, the "historical" one, "Materials for a history of colors."

Our 7th and 8th sections will be devoted to analyzes of the "didactic" and "polemical" part; as for the "historical" part, we shall limit ourselves to quote Young's and Tyndal's opinions (Section 8).

7. Goethe's Theory of Colors, the didactic part: from mystics to physics, from physics to magic[1]

The *Theory of Colors* is composed of six parts, containing 920 paragraphs, plus an introduction and a concluding section. The introduction specifies that "the present essay" is the third attempt to describe and classify the phenomenon of colors, after Theofrastus and Boyle. Although Newton is not included among forerunners (sharing the same fate as Descartes, Hooke, Huygens, Mariotte, etc.), Goethe criticizes Sir Isaac's mistake of having based the study of colors on a secondary phenomenon and neglecting the main one, which could be compared with placing the Moon in the center of our Solar System. The conceptual framework invoked by Goethe is anachronisitc: "the ancient Ionian school … and an old mystic writer," quoting, from this "mystic writer," the following verses: "If the eye were not sunny, how could we perceive light? If God's own strength lived not in us, how could we delight in Divine things?" In fact, this strophe is not written by any "mystic writer," but by Goethe himself, who versifies a fragment of Plotinus's "On beauty," as Cornea notices (2003). If the mystic is invoked in the introduction, the magic will be present, as we shall see, in the last paragraphs. The introduction continues with the presentation—in a triumphalist manner—of the benefits brought by this work "to other pursuits," described in the 5th part.

The first part, Physiological Colors, refers to the light perceived by the human eye, and contains the paragraphs 1–135 (about 15% of the total paragraph number); the second part, Physical Colors, refers both to color perception and to questions pertaining, strictly speaking, to physical optics (paragraphs 136–484, about 38%); the third part, Chemical Colors, refers to dyes and pigments (paragraphs 485–687, about 22%); the fourth part, General Characteristics, is more the promise of a future chapter than a completed one (688–715, i.e. 3%); the fifth part, Relations to Other Pursuits (i.e. philosophy, mathematics, technical operations of the dyer, physiology and pathology, natural history, general physics, theory of music), contains paragraphs 716–57 (about 4.5%); the sixth part, Effect of Color to Moral Associations (paragraphs 758–920), about 18%.

Trying to explain the fact that colors result from the light–darkness polarity, Goethe identifies here the "primordial phenomenon" of the theory of colors, named so "because nothing appreciable by the senses lies beyond it, on the contrary, they are perfectly fit to be considered as a fixed point to which we first ascended, step by step, and from which we may, in like manner, descend to the commonest case of every-day experience" (par. 175). He reproaches Newton for not having recognized this phenomenon and having put, in his explanation on color formation, secondary phenomena before the primordial one (par. 177). The physicist must not only recognize the primordial phenomenon, but also not transgress it in his research: "we are arrived at the limits of experimental knowledge. Let the observer of nature suffer the primordial phenomenon to remain undisturbed in its beauty; let the philosopher admit it into his department, and he will find that important elementary facts are a worthier basis for further operations than insulated cases, opinions, and hypotheses."

This strange interdiction, the origin of which is of course occult, limits in an unacceptably way scientist's freedom and is completely anachronistic, in the context of nineteenthcentury physics.

In spite of all these ideological limitations, the first two parts contain valuable observations, both from the physiological and physical point of view; the issue will be discussed, in detail, later on. For the moment, we shall note that, regardless of blaming the use of instruments for the study of light (and, in general, of nature), Goethe has quite diversified equipment: a cubical vessel (par. 187), concave and convex glass (i.e. lenses, par. 200), a large water-prism (par. 308), or one filled with other liquids (par. 342); a small prism composed of three different prisms, "as prepared in England" (par. 298), etc. It is somehow touching to see how Goethe, already reaching his old age, describes the difficulties of capturing the sun light in the *camera obscura* of his house in Weimar (where there are, on average, 4 1/2 sunny hours daily, accumulated of course from several shorter intervals), of moving his instruments according to the displacement of sunlight, of repeating all Newton's experiments … but this was the only possibility the pantheist priest had to defend nature against the blasphemies of the new physics.

Even if some of his physiological observations are interesting, even if he is, sometimes, closer than Newton to the correct explanations of the apparition of some colors (Duck, 1988), Goethe's attempt to impose Aristotle's theory instead of Newton's is obviously a complete failure. As our study is focused on physics and physiology, we shall not comment the 3rd and 4th parts, and skip to 'the relation of the theory of colors with mathematics', described in the 5th part.

The theory of colors, in particular, has suffered much, and its progress has been incalculably retarded by having been mixed up with optics generally, a science which cannot dispense with mathematics; whereas the theory of colors, in strictness, may be investigated quite independently of optics. (par. 725)[2]

But besides this there was an additional evil. A great mathematician [not physicist!—our comment] was possessed with an entirely false notion on the physical origin of colors; yet, owing to his great authority as a geometer, the mistakes which he committed as an experimentalist long became sanctioned in the eyes of a world ever fettered in prejudices. (par. 726)

"The great mathematician" was not of course able to exculpate himself, but we cannot refrain from remembering one of his replies: "Pray trouble your self no further to reconcile me with truth but let us know your own mistakes."

Finally, it is interesting to mention that the last subchapter of the *Theory of Colors*—therefore, included in the 6th part—is entitled "Allegorical, Symbolical, Mystical Application of Color." We shall quote one of the last paragraphs (918):

> That, lastly, color may have a mystical allusion, may be readily surmised, for since every diagram in which the variety of colors may be represented points to those primordial relations which belong both to nature and the organ of vision, there can be no doubt that these may be made use of as a language, in cases where it is proposed to express similar primordial relations which do not present themselves to the senses in so powerful and varied a manner. The mathematician extols the value and applicability of the triangle; the triangle is revered by the mystic; much admits of being expressed in it by diagrams, and, among other things, the law of the phenomena of colors; in this case, indeed, we presently arrive at the ancient mysterious hexagon.

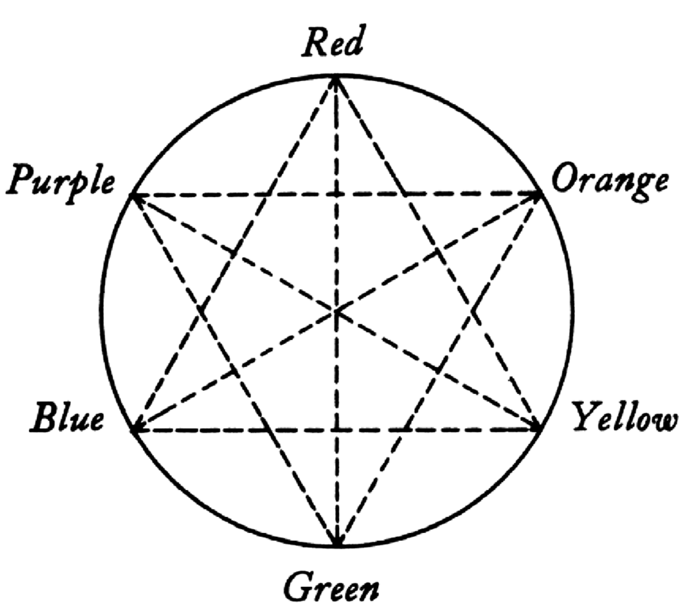
The connections between triangle and colors, suggested in the previous paragraph, can be done, as Grigorovici noticed (Grigorovici, 2013), through the color triangle, inscribed in Goethe's color circle (par. 50 of *Zur Farbenlehre*).

In opposition with Newton, and in consensus with other scholars from the 18th century, Goethe does not complete the circle with spectral (rainbow) colors, but put the red, the green, and the blue in the corner of an equilateral triangle; the essential fact is that the extreme red and the extreme blue do not touch, as in Newton's circle, but they are separated. Goethe colors each point of the segment between the extreme blue and the extreme red with a mixture of red and blue, in proportions given by the distance of that point to extreme blue and extreme red, obtaining various nuances of purple—color which does not exist in the rainbow. If the average purple is represented by a point, Purple on the color circle (see Figure 1), equidistant from Blue and Red, the equilateral triangle, inscribed in circle, having a corner in Purple and the others in Green and Orange, is "upside-down" with respect to Red–Blue–Yellow, and the two triangles form together a hexagon, "the mysterious hexagon."

What is unusual, in this hexagon, for being called "mysterious"? Five of its corners, belonging on the long arch between red and violet, which actually represent the rainbow colors, disposed on the circle, are "natural" colors, i.e. the components of which white light is decomposed. The sixth corner of the hexagon corresponds to purple, which is not a "natural" color, in the sense just explained. Magical thinking can associate this corner with the entrance to the unreal and the supernatural. As Grigorovici remarks, if one puts away this corner, the hexagon becomes a magical pentagram (Drudenfuss, ghost's foot). Grigorovici recalls the scene from "Faust," where the character comes back to his room after a walk outside of the city with a dog, which turns out to be an incarnation of Mefisto. On the threshold of Faust's room there was inscribed the magical pentagram; it allows Mefisto to get in but hampers him in getting out.

The Chorus of Spirits, which shows up in order to save Mefisto, causes Faust to fall asleep, but some rats gnaw the pentagram and Mefisto is freed. Grigorovici sees, in the evocation of the "mysterious hexagon" in the final of his *Theory of Colors*, a replica of the "mysterious hexagon" from *Faust*, showing Goethe's attachment to magic, which is evident through all his work, from his early writings to *Zur Farbenlehre* (Grigorovici, 2013).

Figure 1. The "mysterious hexagon", reproduced from von Goethe (1840). If one removes the small equilateral triangle pointing to "Purple", it changes to the "magical pentagram" (see the explanations at the end of Section 7).



Therefore, in spite of Goethe's intention of producing a scientific critique of the Newtonian theory, his conception of science was antiquated, even stubbornly retrograde; and so *Zur Farbenlehre* is preceded by a preamble with mystical references and ends with references to magic. In the end, therefore, given the trajectory of modern science, Goethe's own "scientific" approach undermines itself by appeal to mysticism and magic. As a result, it played an insignificant role–if any–in the subsequent development of optics and colorimetry.

8. Theory of colors, the polemic part: exposure of Newton's theory

Disregarding the skepticism of all physicists concerning his rejection of Newtonian physics, Goethe remained convinced that he had "clearly demonstrated the extent to which Newton's hypothetical explanations and derivations of the colored phenomena caused by refraction are untenable." Vae victis! Newton is not only defeated, but also severely blamed, in a manner that is merely characteristic of a pamphlet rather than a substantive polemic tract.

"The extremely sagacious Mr. Newton," from Wolff's review, becomes, for Goethe, a bandleader of Cossacks (par.1 78), and his accomplishment in optics—the worst example of shamelessness in the history of sciences (par. 360). His followers, the "illustrious company ... well versed in this argument," as called in *Philosophical Transactions*, should "wear—according to Goethe—special garments so that they could be distinguished from sane people" (par. 572). The idea of imposing discriminatory clothes to a category of people, in order to make it subject to public opprobrium, will be put in practice soon enough. Other compliments offered to Newton and his followers from the Olympian Goethe are listed, with astonishment, by von Helmholtz (1898) and Jaki (1969). In the next section, after a review of the contemporaries' attitude to *Zur Farbenlehre*, we shall see physicists' reaction to these judgments.

9. Reception of Goethe's "Theory of Colors"

9.1. Contemporaneous reactions

Schiller, Hegel, Schopenhauer, and Beethoven praised Goethe's studies of color, which they knew from direct discussions with their author, from their correspondence (Schiller's case), and from the books themselves. Schopenhauer was one of the few of Goethe's followers who tried to extend and develop *Zur Farbenlehre*. He associated numbers to spectral colors, trying to explain the retina's activities and afterimages, and he argued that Goethe's urphänomen is not archetypal but is produced by properties of retina (Zemplen, 2006). Reading Schopenhauer's manuscript, Goethe rejected his innovations—we can imagine that both the use of numbers and the re-definition of the urphänomen disappointed him—and he refused to write an introduction to the young philosopher's work. Finally, in 1815, Schopenhauer sent to print his book about vision and colors without any encouragement from Goethe (see Zemplen, 2006, Ref. 56).

Two years later, a mathematician from Weimar, Johann Werneburg, published an attempt to introduce "the art of measuring" into Goethe's work (see Zemplen, 2006; Ref. 61). Werneburg shares not only Goethe's views on colors but also his intransigence against criticism ("to all those that ruminate and demand a *foramen exignum*, the resort must be: Out of the way! Out of the way! Make way! ...") (Zemplen, 2006). His treatment at Goethe's hands is, however, no more positive than the Newtonians, as Goethe writes dismissively and perfunctorily in a letter to Zelter that Werneburg is "making things easier for himself" but "more difficult to others" (Zemplen, 2006).

Goethe's sympathy, in contrast, goes to one of the most gifted German romantic painters, Philipp Otto Runge. Runge was aware of Tobias Mayer's works, and he adopted yellow, red, and blue as basic colors of a trichromatic system. In his color circle, he inscribes an equilateral triangle, having yellow, red, and blue in its corners and, together with an opposite one (symmetrical with respect to the center of the circle) with pairwise mixtures in its corners. In this way, Runge obtains a hexagon. He extends the color circle to a color sphere. This direction of "color science" was extended by Chevreul (1839) and Munsell (1900) (see the article on Runge in Wikipedia). Runge's paper has no quantitative aspects and discusses the harmony of colors from the perspective of art. This approach was praised by Goethe, and Runge's contribution is included in *Zur Farbenlehre*.

9.2. Physicists of 19th and 20th century

Goethe explains, in the fifth part of *Zur Farbenlehre*, Relations to Other Pursuits, why the physicists should be grateful to him as beneficiaries of a correct theory of colors. Alas! He is forced to accept that among his supporters "there was not a single physicist" (Ref. 26 of Jaki, 1969). H. W. Branders, professor of the University of Leipzig, stressed from the very beginning that Newton's *Opticks* needs as little defense as the Copernican theory. Many German scholars of his time, however, avoided to take a stance on *Zur Farbenlehre*. This is not the case with other physicists of great scientific achievement, contemporaries or not with Goethe, starting with Thomas Young, the discoverer of the interference phenomena (and one of the contributors to the decipherment of hieroglyphs), and ending with Wien and Heisenberg, Nobel Prize laureates. Thomas Young, probably the most brilliant specialist in the science of colors of the beginning of the 19th century, finds in the Historical Part of Goethe's text, "some industry but little talent, and less judgement" (Jaki, 1969, Ref. 30). He also carried out an experiment, described as "crucial" by Goethe, but he observed the opposite to what the poet had claimed to take place. Young's global perception is that Goethe's theory represents "a strange perversion of human faculties." This opinion is still the most quoted diagnosis of *Zur Farbenlehre*.

Other scholars reached similar verdicts. For Etienne-Louis Malus, Goethe "is not in the state of mind appropriate to those who sincerely seek the truth" (1811) (Sepper, 2003, p. 3) "As he condemns indiscriminately all statements of the science of optics, it is not in his book that one should dare search for errors that Newton might have committed." (Jaki, 1969). For Brewster, Goethe's "methodology" is dangerous, as it reflects a mentality in which "the slightest resemblances, the most fortuitous associations are linked together as cause and effect" (1840). He was concerned by the Eastlake's claim that *Zur Farbenlehre* is "more applicable to the theory and practice of painting than the doctrines of Newton and his followers," though it would be a "cultural disaster," observes Brewster, to place "the principles of art in direct alliance with error." A similar warning had been formulated by Young some three decades earlier.

Sir Arthur Schuster notices a logical contradiction of Goethe's approach: his "Theory of colors" renounced the quantitative analysis of light and colors, while claiming to offer a full treatment of colors. Also, he censured (as Heisenberg did later) Goethe's uncritical trust in the reality of the common sense world. John Tyndall did a detailed analysis of *Zur Farbenlehre*, without omitting its merits ("of rather limited value") but concluding that Goethe "was wrong in his intellectual and perverse in his moral judgements." He failed to understand the spirit of tolerance and pluralism which nature is capable of exhibiting when it inspires both poets and scientists (Jaki, 1969; Ref. 42). Helmholtz is the first great German physicist to speak about *Zur Farbenlehre*. In a lecture addressed to the Königsberg branch of Deutsche Gesellschaft in 1852, his critique is severe and consistent (see Ref. 36 in Jaki, 1969). Forty years later, accepting the invitation of the Goethe Society in Weimar, Helmholtz adopts a more diplomatic position. He avoids speaking about Goethe's anti-Newtonian stance and emphasizes what a humanist and a physicist have in common. An ambiguous position has also Wien, a Nobel laureate, in a lecture given in 1923. He considers that Goethe, "imbued with pantheism, felt confident that his genius could establish an intuitive contact with the world-spirit and gain thereby an all-embracing knowledge of nature" (Jaki, 1969), but his approach is not convincing for a scientist. At the end of his talk, however, Wien makes a surprising and disappointing concession to Goethe, speaking favorably about his view that magnetism would be an *urphänomen*. Let us also mention Sommerfeld's conclusion: Goethe did not possess the temper and qualities of a systematic investigator of nature (Jaki, 1969, Ref. 43).

In the '40s and '50s of the 20th century, when humankind was confronted with a dramatic risk of self-destruction, several physicists of German origin or education—

Heisenberg, Heitler, Born, von Weizsaecker—praised Goethe for his effort of global perception of nature (Jaki, 1969). For instance, Heitler considers that the main task of a scientist is forestalling the further dehumanization of human beings by modern technology and by its spurious quantitative philosophy. For such reasons, Born—a Nobel laureate—writes that we should learn from Goethe "not to forget the meaning of the whole amidst the fascination of details." Heisenberg mentions that "Goethe's physics" are more complex and even seem to imply mathematical thinking in their use of symmetries.

9.3. For many, Goethe is too dear a person …. (Zemplen, 2006)

Goethe's prestige, consolidated by his impressive literary production, inhibits the criticism of several of his exegetes. "The slightest resemblances, the most fortuitous associations are linked together as cause and effect": if Goethe is describing the colored shadows, one century and a half after Otto von Guernike, he is considered the discoverer and the first researcher of these images. If he claims that the practical man, the dyer, is happy to see a reasonable theory of colors emerging (*Zur Farbenlehre*, of course), Goethe's approach is pluralistic and democratic, as opposed to the despotic and tyrannical Newtonian school (Zemplen, 2001, note 145). A sample of "democratic" science is given by a transcription of one of Steiner's physics lectures: "Steiner: [you should see] a monochromatic gray; isn't that right? Or did you see anything else? Audience: Purple… reddish… Steiner: Yes, that's because the red is somewhat too strong […] I did try to compensate for that by giving it less space… if the arrangement were completely right, you would actually see a monochromatic grey" (Zemplen, 2006, note 71). In fact, with any arrangement the audience could not see "a monochromatic grey" due to the simple fact that gray is not monochromatic.

Even the most embarrassing terminological confusions are not avoided, if they can put in a favorable light the "too dear a person." The boundary colors have nothing to do with the boundary conditions imposed to the solutions of differential equations, as Ribe (1985) suggests, but this produces "an analogy between Goethe's modificationist model and differential equations" (Zemplen, 2001, p. 61). The fact that, in a manuscript, "Goethe derives straight-lines boundaries from a curved boundary" (Zemplen, 2001, p. 61), becomes, for Sepper, a continuous deformation of space (Sepper 2003). Actually, the space is exactly the same—it can be approximated by an Euclidian plane—and Goethe is simply drawing lines in this space. (For an example of "continuous deformation of space," see for instance an animation in Wikipedia (https://en.wikipedia.org/wiki/Topology#/media/File:Mug_and_Torus_morph.gif). Let us end this enumeration with Kundera's opinion: "In his youth, Goethe studies alchemy, but later on, he becomes a pioneer of modern science." Goethe, as we could see, was an enemy not a pioneer of modern science, but his huge cultural prestige acts as a magnifier of his scientific merits.

Looking for a key to understanding Goethe's surprising position with respect to colors and, more generally, to Newtonian physics, one must penetrate deeper into his existential experiences, cultural, and educational influences, and personal idiosyncrasies. Indeed, they can be seen quite clearly in literary works, mainly in his autobiographical writings (von Goethe, 1848), in his rich correspondence, and in *Faust*. We hope that at the end of this investigation the explanation for Goethe's anti-Newtonianism will be evident.

10. Countless Goethe's facets: the spectral decomposition of an *uomo universalis*

10.1. Goethe and antiquity

Goethe's attachment to Antiquity resonates with the cultural orientation of his generationand is connected, at least in part, to the socio-political situation in Germany. In reality, each of the significant European countries forged its own path from the Middle Ages to modernity: France, through political revolution; Russia, through reforms imposed by energetic sovereigns; and England, through industrial revolution. Germany, divided into 300 small states, could not choose any of these paths. At the end of the18th century, the German intelligentsia attempted to surpass the contradictions between its medieval inheritance and Enlightenment openness by reconciling itself with society and nature using an ancient model and—especially—that of the Greeks. The idealization and praise of the serenity of Antiquity are, in the works of German neo-humanists, compensation for the anxieties of the time. Goethe's literary and scientific work is no exception (Vianu, 1955).

For Goethe, the *uomo universalis* of classicist style, the Italian journey was an existential accomplishment that directly provided him the meaning of Antiquity and transformed him into a being "in harmony with himself". "It is in Antiquity, that Goethe is looking for the 'human'; Antiquity shows up, according to him, as the 'primordial phenomenon' (Urphänomen) for the man; and his way of understanding Antiquity represents the way he can understand the man" (Noica, 2000, p. 88).

Although Italy delights Goethe from the landscape, architectural and pictorial points of view, the Greek spirituality is closer to him than the Roman one. In the world desired by Goethe, at least in his late years, "anyone should be, in his own way, a Greek" (Noica, 2000, p. 88). He regretted that Latin, not Greek, became the language of Middle Ages science; in a letter to Zelter (23 March 1827, see Noica, 2000, p. 112), he confesses that, if he were younger, he would fully devote himself to Greeks: "nature and Aristotle would be my objectives".

Goethe, as a thinker, considered himself to be a man of his time, if not a forerunner to it; however, he is in fact, a pre-Socratic, placed somewhere between Thales ("The principle of all things is water, all comes from water, and to water all returns") and Protagoras ("Man is the measure of all things"). Goethe seems to have a special sympathy for Thales. Indeed, Thales is the only philosopher who appears in the long cortege of mythological and historical characters that occupies the largest part of *Faust II* (and almost completely suffocates the dramatic tension of the play). Goethe shares with the Ionian school the concern of finding, in the multitude of forms and manifestations of nature, an ultimate principle: 'primordial phenomenon'.

Let us recall that the path from the naive Ionian philosophy to the highest forms of the Ancient science goes through another Greek invention—the axiomatic-deductive organization of mathematics. The roots of these inventions are not to be found in the study of nature or of speculative sciences, but in "the freedom of speech provided by Greek democracy, a political and social system in which different parties fought for their interests by way of argument … everyday political argumentation constituted a model for mathematical proof" (Jahnke, 2012). This pre-eminence of the social has consequences. The most amazing achievements of Greek science pertain to astronomy, but even in this case, preconceptions might defeat the scientific approach if they endanger fundamental representations. The Greek meaning of perfection claims that planets must move on circular trajectories at a constant speed, and to conciliate this claim with observational data, astronomers make artificial hypotheses deprived of any dynamical basis; but, in this way, they "save the phenomena". This approach is adopted by Goethe for optics, where he is "in agreement [with physicists] about the facts but in violent contradiction about their meaning" (von Helmholtz, 1898). He perverts, in an unacceptable manner, the explanation of experiments to save Aristotle's conception of colors, which is his own way of "saving the phenomenon". The Goethean science, as it is, represents a return to the Greek mind (Berthelot, 1932 cited by Noica, 2000, p. 70). However, this type of option for classicism does not manifest only in science. For instance, Goethe's attachment to classicism is so strong, as it favors a visible reticence with respect to romanticism, even in musics.

10.2. Goethe and art

To Goethe, the study of light is by no means limited to physical and physiological aspects, but it is central to the esthetical understanding of the world, the fine arts, and, primarily, painting. This remark is essential for a correct evaluation of the "Theory of colours"; for this reason, we shall now discuss the role played by art in the Goethean system of values.

Goethe was shaped in a milieu imbued with art. As a child, Goethe was brought by his father to the studios of renowned painters in Frankfurt, took part in auctions and gained a precocious renown because he was able to immediately discern the meaning of a painting of sacred or profane history or mythology. Additionally, he was even able to suggest subjects to painters. He took design lessons, to the satisfaction of his father, who was a passionate and competent art collector. During his student years in Leipzig, he took private lessons with Oester, the director of the Academy of Design, a close friend of Winckelman, the founder of modern archeology. At Strasbourg, in the respite granted by the study of law, he painted in oil in a professionally arranged studio (under Nothnegel's supervision), and engraved. During his long Italian journey, he lived in Rome, in Tischbein's house; he made copies in the Sistine Chapel, or drawings of the ruins of the Capitolium and of via Appia.

Goethe has a primordially visual understanding of world. "The eye was, above all others, the organ by which I seized the world. I had, from childhood, lived among painters, and had accustomed to look at objects, as they did, with reference to art" (von Goethe, 1848, p. 187). "The manifold subjects which I saw treated by artists awakened the poetic talent in me, and as one easily makes an engraving for a poem, so I did now make poems to the engravings and drawings, by contriving to present to myself the personages introduced in them, in their previous and subsequent condition, and sometimes to compose a little song which might have suited them; and thus accustomed myself to consider the arts in connection with each other." (von Goethe, 1848, p. 268).

The understanding of color is therefore, for Goethe, an essential component of understanding the world, integrated in a comprehensive philosophical and religious system. Dissecting the light in experiments and treating it using mathematical abstractions were resented as an attack on the beauty and coherence of the world. This perception is at least partially responsible for his violent reaction against Newtonian optics.

10.3. Goethe and the study of nature

Goethe's scientific education is respectable and complex. In Strasbourg, he took courses in chemistry, anatomy, clinical medicine and midwifery (von Goethe, 1848). He studied chemistry using Boerhave's treatise and, in the private laboratory of Miss von Klettenberg, worked with a small oven, containers and retorts, under Welling's guidance (from "Opus magno-cabbalisticum") and under the supervision of a physician who was well known in town; he was proud of the ease with which he prepared liquor silicum (sodium silicate, Na_2SiO_3, or water glass or liquid glass). He studied both chemistry and medicine from Paracelsus' perspective. His mystical-religious studies kept him away from literature, to which he returned under Herder's influence (von Goethe, 1848). Goethe could not deprive himself of literature, just as he could not deprive himself of occultism, as for him, the understanding of nature must be global. "The result of all my thoughts and endeavors was the old resolution to investigate inner and outer nature, and to allow her to rule herself in loving imitation" (von Goethe, 1848, p. 469).

No phenomenon or experience seemed uninteresting to Goethe. He attempted to construct an electrostatic machine (von Goethe, 1848); he noticed and recorded unusual optical atmospheric phenomena: "Yet I was indebted to this damp weather for the sight of a natural phenomenon which must be exceedingly rare …" (von Goethe, 1848, p. 203). During his journeys, he took the opportunity to study geography in a very personal way, acquiring "a general survey of every stream-region, in which one happens to be, a conception of heights and depths which bear relation to each other, and by these leading lines, which assist the contemplation as well as the memory, extricates oneself in the surest manner from the geological and political labyrinth" (von Goethe, 1848, p. 360). In Switzerland, he climbed "wild mountains, in a complete solitude and wilderness" (von Goethe, 1848).

Goethe was interested in geology, and he had the richest collection of rocks in his time. Unfortunately, his conception of Earth history is undermined by his horror of the catastrophic—that is, relatively sudden and profound disruptions of the order of things (Noica, 2000, p. 80). In geology, he refuses to acknowledge a "volcanist", irruptive and catastrophic period in the history of Earth, and argues for a thesis of slow development. He is not only "antivolcanist" but also "anti-neptunist" (here, in the sense that he perceives the influence of water to be catastrophic): "where they see only uproar, for us, everything happens peacefully and quietly" (Noica, 2000, p. 80).

Various practical activities fascinated him, and he devoted time to them. He bred silkworms under his father's guidance; he kept an eye on the rehabilitation of his native home in Frankfurt as a child; in the same years, he was fascinated by the oil cloth factory; "...occasionally lent a hand myself" (von Goethe, 1848, p. 128). He practiced gardening; "... gardening matters ... as they were repeated every year, became in the end perfectly known and familiar to us". The journey to Alsace taken during his years as a student in Strasbourg, awoke his interest in technical and economic issues, which dominated a long part of his life. On the same occasion, he visited a glass factory in Friedrichstal.

He took a special interest in biology. "I pulled flowers to pieces to see how the leaves were inserted into the calyx, or even plucked birds to observe how the feathers were inserted into wings. Children are not to be blamed for this, when even our naturalists believe they get their knowledge oftener by separation and division than union and combination, - more by killing than by making alive" (von Goethe, 1848, p. 95). Here, we can perceive a subtextual attack on Newtonian physics. However, the analysis and synthesis, the separation and the unification are complementary operations, compulsory in the systematic investigation of a certain domain. Goethe seems to disfavor, for strictly subjective reasons, the analysis to support synthesis, which is unacceptable as a scientific methodology.

In spite of its extent, Goethe's knowledge remained, in general, at a relatively superficial level, except for his knowledge pertaining to certain descriptive disciplines. Even more serious is the constant vitiation of his scientific thinking by occultism and idiosyncrasies. "I had also [like Faust, our note] wondered about in all sorts of science, and had early enough been led to see its vanity" (von Goethe, 1848, p. 357). The vanity that disappoints Faust is the vanity of medieval sciences, not that of Newtonian science. Goethe wonders at science; he does not study it systematically, and he is psychologically closer to the Middle Ages scholars than to the scholars of his time.

10.4. Goethe and religion

As a child, Goethe built a small shrine for himself in which he was celebrated as a true pantheist priest (von Goethe, 1848). Later on, he believed that "every man has his own religion at last, so nothing seemed more natural to me than that I should form mine too, and this I did with much satisfaction. The Neo-Platonism laid the foundation; the hermetical, the mystical, the cabalistic, also contributed their share, and thus I built for myself a world that looked strange enough" (von Goethe, 1848, p. 300). However, he was wise enough not to unveil these forms of religiosity to Herder.

Goethe believes in the innocence of humans and nature (Noica, 2000, p. 49)– a position that can hardly be reconciled with institutionalized Christianity. This institution is accused to have committed a similar sin as Newton's: the Church divided God into three, and Newton divided God's most unique and pure creation [light] into seven (see Duck, 1997; Schoene, 1987). In a letter to Jacobi, Goethe confesses that, in some respects, he is monotheist, in others, polytheist, and while researching nature, he is pantheist (Noica, 2000, p;.119). However, even as a researcher of nature, he is interested only in "the nature which reveals God, not that which hides him" (Noica, 2000, p. 119). His position is quite similar to that of the light metaphysicians of the 17th and 18th centuries, such as Hutchinson (see Duck, 1997).

10.5. Goethe's pantheism, anthropocentrism and egalitarianism

Goethe has a deep feeling of egalitarianism. A sample of folk wisdom, written inside the Frankfurt Town Hall, (One man's word is no man's word,/Justice needs that both be heard von Goethe, 1848) pursued him all his life, and unfortunately, he sometimes applied it to mean that "one man" may be Newton, proposing *experimentus crucis*, or Copernicus, proposing the heliocentric system. He had a deep esteem for those who practiced egalitarianism, quite numerous in Germany at the time.

He admired those who donated their own fortune to the municipality of Frankfurt, and eulogized "that tendency to humility and equality, which in the second half of the last century [XVIIth] was manifested in so many ways, from above downwards, and broke out in such unlooked for effects" (von Goethe, 1848, p. 58). Let us quote an opinion that would horrify a reader who lived during the totalitarianisms of the 20th century: "only mankind together is the true man, and … the individual can only be joyous and happy when he has the courage to feel himself in the whole" (von Goethe, 1848, p. 58).

His anthropocentrism makes Goethe perceive the heliocentric model to be a great challenge, if not humiliation, to humanity, forcing "man to renounce his huge privilege of being in the centre of the Universe". His aversion to heliocentrism is so strong that the archangel who praises the greatness of Universe, in the first verses of the prologue to *Faust*, does not follow a Copernican model or even that of Ptolemy, but that of Phylolaus, a Pythagoreic from the 5th century b. Chr.

Goethe's egalitarianism, like his anthropocentrism, has no reasonable limit. According to Goethe, every man has the right to build his own religion, as mentioned above. Theological competence does not play any role, and in the same way, scientific competence has no right to limit individual options. "Every man has his quirk, Copernicus has his too". This statement is a form of intellectual anarchism through which Goethe once more undermines his capacity as a researcher of nature. Egalitarianism must be applied in the political and social realm, but under no means in science, which remains elitist. The truth cannot be established in a plebiscitary manner, and science cannot be built on the accumulation of quirks, but through the critical analysis and sedimentation of knowledge acquired by the most illustrious minds of humanity.

10.6. Goethe's philosophy of nature, between agnosticism and magic

Goethe has no passion for philosophy, and he has a true antipathy for logic.

> At first I attended my lectures assiduously and faithfully—writes Goethe about his student years—but the philosophy would not enlighten me at all. In the logic it seemed strange to me that I had so to tear asunder, isolate, and, as it were, destroy those operations of the mind which I have performed with the greatest ease from my youth upwards, and this in order to see the right use of them

(von Goethe, 1848, p. 208). He has an even more pronounced aversion toward atheistic philosophy. After having read d'Holbach's *Systhème de la nature*, he wrote, "…we took a hearty dislike to all philosophy, and especially metaphysics, and remained in this dislike; while, on the other hand, we threw ourselves into living knowledge, experience, action, and poetizing, with all the more liveliness and passion" (von Goethe, 1848, p. 208).

Of course, it is not the excess of metaphysics for which d'Holbach should be blamed, but Goethe does not miss any occasion to show his aversion to speculative thinking. "We had neither impulse nor tendency to be illuminated and advanced in a philosophical manner."

"I am a very terrestrial man… - he writes to Lavater in 1779—and I also like to be on the truth side, but the truth of the five senses." However, as Noica notices, this truth is suppressed by itself, as it cannot be theorized (Noica, 2000, p. 38).

The abyss between Goethe and philosophers pursued him until his late years. "Kant never noticed me…"—he confesses with sorrow to Eckermann (on 2 April 1827, quoted in Noica, 2000, p. 114). Reciprocally, it seems that Goethe did not spend much time studying the works of the great philosopher. However, in spite of this inadequacy, Goethe makes very profound remarks about Kant, and his opinions are the first to be quoted in the introduction to the celebrated monograph of Cassirer (2001) devoted to the criticist from Königsberg. Regarding Hegel's philosophy, Goethe says that it simultaneously attracts him and is repugnant to him. He asked Fichte to help him reconcile with philosophers, "as I cannot be without them, but however with whom I could never agree" (Noica, 2000, p. 114).

However, reconciliation was impossible because Goethe "does not understand the vivid contradiction, the dialogue which can lead to dialectics", to use Noica's words (Noica, 2000, p;.114). In a letter to the chancellor von Müller, Goethe declared that he was increasingly less interested in opposing others and their way of thinking: "In fact, I cannot think like him, because I am me and not him." (1 February 1826) If dialectic structures are stimulated through contradiction, logical ones (Goethe's case) become retractile and inflexible (Noica, 2000, p.132).

"In fact, for philosophy, I had no organ" (quoted in (Noica, 2000, p. 139), Goethe confesses, and philosophy did not operate with Goethean-like intellectual intuition (Noica, 2000, p. 139). Even less did physics.

The Goethean philosophy of nature—as much as it is—is based on three ideas: the idea of polarity (or dualism), that of the primordial phenomenon, and pantheism.

"Who does not accept a fundamental dualism, as spirit—matter, soul—body, thinking –extension [of course we can include the light - darkness dualism, our comment], both of them as representatives of divinity, has to renounce thinking." (letter to Knebel, 8 April 1812, quoted in Noica, 2000, p.122). Some dualities are "primordial", such as the case, in the theory of colours, with the duality light—darkness; it is considered by Goethe to be an *urphänomen* because beyond it, there is nothing in the phenomenal world, as explained in the "didactic part". Therefore, an attempt to explain the colours by a philosophy other than the polarity light—darkness is equivalent for him to renouncing thinking.

Goethe's position, as a researcher of nature, is merely an agnostic one. "The highest moment a man can reach is astonishment; and, if the primordial phenomenon puts him in state of astonishment, he should be satisfied; more than that one cannot offer to him, and more than that, he should not seek; there is the border", Goethe said to Eckermann. Again: "Nature has no system; it has, it is the life itself; it is coming from an unknown centre, toward an unknowable border. …Truth can be never known directly by us; we can see it only in reflexion, in symbol. … If in the end I stop at the primordial phenomenon, this too is a form of resignation". Goethe's oscillations between various levels of cognoscibility of the world are the object of a detailed and subtle analysis by Zemplen (2001).

The thing-in-itself is recognized and rejected simultaneously: it is Goethe's double tendency, part of his mystical oscillation between revelation and mystery: "The Ever-Nameless that unriddled seeing", as he writes in the *Marienbad Elegy*, or, in some other place, "Mystery sacredly revealed". Therefore, the mystical conscience sees everything, as Noica notes.

It is strange that Goethe's agnosticism is largely an assumed one; it does not reside merely in the character of knowledge, but rather in the researcher's voluntary attitude, which decides that a certain threshold cannot be transgressed. This threshold refers, at least in the theory of colours, to the transition from the sensorial perception to the abstractization.

Goethe's aversion to abstractization has been analysed by Heisenberg. The great physicist begins with the following paragraph of the introduction to the "didactic part": "Every act of seeing leads to consideration, consideration to reflection, reflection to combination, and thus it may be said that in every attentive look on nature we already theorize. But in order to guard against **the possible abuse of this abstract view** [our emphasis], in order that the practical deductions we look to should be really useful, we should theorize without forgetting that we are so doing, we should theorize with mental self-possession, and, to use a bold word, with irony."

The abuse consists of replacing intuition with abstract thinking. The real world should not be abandoned, one should not enter the abstract world, and one should not break "the mysterious hexagon". The dangers brought by this action are not detailed by Goethe, even though they are obsessively mentioned; however, they could be guessed from *Faust*. The secret signs from Nostradamus' book, investigated by Faust (and also studied by the young Goethe), find an equivalent in the symbols of modern mathematics. (In reality, as explicitly stated by Goethe, in the didactic part of *Zur Farbenlehre*, mathematics that try to grasp the secrets of nature appear to him as a kind of cabalistic symbols, typical of the Middle Ages.) Following this line, Faust invokes Earth Spirit (Arhaeum Terrae), who scares him, and finally arrives at Mephisto; consequently, he endangers his redemption and his eternal life. Faust reproaches to the Arhaeus Terrae that he sent him to Mephisto, but this is just a consequence of Faust's forcing the borders of knowledge by using "abstractization".

In addition, it is unacceptable to blame abstractization because—as Heisenberg notes (see also Schuster's comment, in Section 8)—there is no indication that the most profound correlations describing the laws of nature can be so directly visible that they can be described in abstraction-free language.

10.7. Goethe and physics

Goethe not only sees himself as the greatest connoisseur of the theory of colors but also believes he has a calling to physics. "God has cursed you with metaphysics, and has blessed me with physics", he writes to Jacobi on 5 August 1786 (quoted in Noica, 2000, p.170).

Goethe the physicist does not care for laboratory devices because "man is, in himself, the greatest and most precise apparatus of physics. And exactly here is the disaster of new physics, that it almost separated the experiments from man, and it wants to know nature … only by what these artificial devices show to him" (letter to Seller, 22 June 1808). This is why astronomy—in which the use of an apparatus seems, even for Goethe, unavoidable—was not attractive to him. In spite of Goethe's repulsion for all "artificial instruments", including glasses, he made use of them in his fight against "the new physics".

The explanation of such ambiguities should probably be found in Goethe's double capacity as a researcher and a pantheist priest. He feels obliged to analyze Newton's theory, much as the official theology has to analyze various theses to dismiss various possible heresies. From this position, Goethe uses "artificial instruments", and the heresy is finally unmasked and blamed. Illustrative for the pantheism of Goethe-the-physicist is also the reply he gives to Benjamin Thompson, when the latter conjectures that the colored shadows might be optical illusions: "It is a blasphemy to say there is such a thing as an optical illusion!"

Newton—like any genuine physicist—regretted that the borders of cognoscibility are too far away. However, Goethe-the-physicist is anxious to transgress these borders and, in this way, perturb the primordial phenomenon. In fact, such a perturbation would be of no use, as "whichever way we might know the world, it will always keep a daytime and a nighttime face" (see Noica, 2000, p. 144).

Countless examples from the history of physics have shown that the absolute freedom of thinking is an essential condition of efficient research. The constraints imposed on researchers by various authoritarian regimes have always had negative consequences. The primacy of ideology imposed by the "Goethean methodology" risks transforming the research of nature into a continuous "saving of phenomena": a waste of energy and a deviation from the normal process of knowledge.

Given this section, in which we described Goethe's personality using almost entirely his own judgments to avoid any subjective opinion, we are better prepared to understand the sources of his aversion to Newtonian physics.

11. The sources of Goethe's anti-Newtonianism

Goethe was 40 years old when he began to be concerned about the problem of colors; therefore, he was an already formed and experienced man. Namely, he was formed in a cult of classicism, where the supreme authority is Aristotle; therefore, he was inclined to adopt the Aristotelian theory of colors. We have already seen that some atmospheric phenomena—for instance, the change in the color of solar light from bright white into increasingly darker nuances of red and violet, seems to be associated with the interaction of light with darkness. For the correct explanation of such phenomena, physicists had to wait until the middle of the 20th century, when the scattering of light on atoms and on various microscopic particles from the atmosphere was finally understood. Goethe's attention to meteorological phenomena is likely to have contributed to his embracing of Aristotle's theory. Goethe's interest in painting, where white and black are two substances kept in similar tubes, facilitated the perception that light and darkness are two entities with equivalent ontological status. The use of black to obtain various nuances of colors probably favored the conviction that its presence is essential for color creation.

Goethe's pantheist understanding of nature—seeing in light a divine presence—his obsession with perceiving the manifestations of nature in a global form, the association of laboratory investigations with the risk of violating the frontiers of knowledge, which could make you Mephisto's prisoner and consequently deprive you of eternal life—made the Newtonian science unacceptable.

However, to study nature in the laboratory also means to ignore esthetics. "What is wrong with these Newtonians?…" who want to explain the lively phenomenon of colors with inanimate devices and formulas, "without asking themselves if there are not also painters, beautiful colors and pretty girls" (letter to the painter Stieler, 26 January 1829, see Noica, 2000, p. 62), asks Goethe, in puzzlement.

Goethe is not a dialectic structure and is unable to change a mind ossified by time, by the education received in his early years, and by his own idiosyncrasies. He perceives criticisms as attacks. "All the attacks of my opponents only served to help me see human beings in their weakness", as he confesses to Eckermann (1823). The only concession Goethe makes, in his fight against Newton, is the request, as a last wish and will plea, he made of Eckermann on 15 May 1831 (10 months prior to his death), to exclude from his work the polemic part of the theory of colors, as all that is polemic is contrary to his soul.

Goethe attempts to save nature from the assault of technique, in Helmholtz's words, or, he is trying to save, like Noah, the entire world, but the deluge to come will not be the deluge of nature, but that of man—in Noica's words (Noica, 2000, p. 17), the deluge of unlashed science and of historism, the deluge of a technique out of any control, the deluge of revolutions without any ethical norms. However, of course nobody, not even Goethe, could succeed in such an endeavor.

12. Goethe's physiological observations

Beginning with the observation of colored shadows or of optical illusions—as already mentioned, a term considered blasphemous by Goethe, as it offends the effective properties of color and the divine message it conveys—Goethe reached the conclusion that "to seek a purely external and objective definition of color is to misunderstand what it is". He is, of course, unaware of the fact that Newton had a clear understanding of this fact. However, the previous remark is the starting point of Goethe's interest in image perceptions of the human eye in the absence of any external light excitation, in afterimages, in visual adaptation to light and colour or colrs seen when the eye suffers a blow or pressure, and other phenomena. He enlisted the aid of the physiologist Samuel Thomas Soemmerring and conducted experimental investigations of these colors; for instance, cases of color blindness that were brought to his attention (Sepper, 2003).

Hereafter, we analyze the validity of Goethe's physiological consideration, discussing from a modern perspective several paragraphs of Part I, "Physiological colours". Such analyzes are very scarce (Barris, 2002; Chance, 1932), but the subject should at least be included to have an idea about the dimension of Goethe's interest, and, sometimes, competence, in domains very distant from the literature. As Barris (2002) discussed paragraphs 9, 12, 44, 52, 54, 75, we shall focus here on different paragraphs, namely 115–118.

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§115. If the eye receives a blow, sparks seem to spread from it. In some states of body, again, when the blood is heated, and the system much excited, if the eye is pressed first gently, and the more and more strongly, a dazzling and intolerable light may be excited.

Goethe is referring here to the retinal response ("phosphene") that can be produced without direct light stimulation. These effects were described by the ancient Greeks and Isaac Newton, among others.

Phosphenes can be directly induced not only by mechanical, but also electrical or magnetic stimulation of the retina or visual cortex. The most common phosphenes are pressure phosphenes, caused by rubbing the closed eyes. Another common phosphene is described as "seeing stars" after a sneeze, a heavy cough, blowing of the nose or a blow on the head. Phosphenes could also be created by electrical and/or magnetic stimulation of the eye or the brain.

If the subject experiences a darkening of the visual field that is opposite the point the finger touches, a diffuse colored patch ("glowing circle") that also moves against the rubbing, or a scintillating and deforming light grid with occasional dark spots. These phosphenes are changing very quickly in size, shape, color and location, depending on the force and location of the applied pressure.

The exact scientific explanation is still under debate, but the quasi-general consensus is that pressure on the eye results in the activation of retinal ganglion cells in a similar way to activation by light. The difference is that light stimulates the photoreceptors (the first neuron of the visual pathway) by photochemical transduction and produces an electrical impulse which travels on forward toward the visual cortex of the brain, and mechanical stimulation produces an electrical impulse directly on the ganglion cells (the second neuron of the visual pathway).

§116. If those who have been recently couched experience pain and heat in the eye, they frequently see fiery flashes and sparks: these symptoms last sometimes for a week or fortnight, or till the pain and heat diminishes.

A clinical explanation is hard to find for this paragraph, firstly because the author refers to the symptom of "heat in the eye" which has no clinical equivalent: since the eye is a relatively small organ, located on the exterior of the body and it has small caliber blood vessels, ocular fever doesn't occur.

The single ophthalmologic explanation for this hypothesis is an acute eye disease which could both justify the need for bed rest, the ocular pain and the prolonged flashes. For example an acute glaucoma, a condition in which the eye pressure usually triples at around 50-60 mm Hg, could produce flashes in the absence of light stimulation, due to an intraocular mechanical pressure on the retinal ganglion cells. However, it seems that Goethe does not envisage such a situation (Dumitrache, 2005; Kansky, 2007).

§117. A person suffering from earache saw sparks and balls of light in the eye during each attack, as long as the pain lasted.

This seems to be, if not an error, just an exceptional medical case that caught Goethe's attention. It is most likely that this patient had more than an usual earache/otitis in order to produce phosphenes. An orbital cellulitis (a severe infection of the orbital tissue outside the eye, usually secondary to sinusitis, which causes pressure on the eye from the outside) could explain the flashes and other visual symptoms and also sinus and/or ear pain. This would truly be an exceptional medical case, so as a rule, this assertion is false.

§118. Persons suffering from worms often experience extraordinary appearances in the eye, sometimes sparks of fire, sometimes specters of light, sometimes frightful figures, which they cannot by any effort of the will cease to see: sometimes these appearance are double.

This paragraph is probably the most accurate of Goethe's ophthalmologic descriptions, and it refers to ocular involvement in cases of parasitic disease. Many worms can originate from animals and infect human hosts; a patient with an untreated systemic parasitic infestation can often develop a secondary ocular involvement, which is usually immune-mediated, instead of an intraocular worm presence. The immune inflammatory response affects the uvea (the middle layer of the eye), and one of the first symptoms noticed by these patients is vitreous floaters (intraocular condensations consisting of inflammatory cells that simply float inside the intraocular fluids/vitreous gel). This symptom is called "myodesopsia", and such a patient would see in the visual field a variety of moving dark spots and lines, which Goethe describes as "frightful figures". Phosphenes ("sparks of fire") can also occur if vitreo-retinal traction is present. Because it is an immune-mediated condition, bilateral ocular involvement is frequent; thus, "these appearances are double".

In conclusion, Goethe's physiological observations show quite a deep interest in the pathologies of the eye and a serious effort to scientifically explain them. However, his personal contribution to ocular physiology is minimal, as most of his comments were passed on to him, as they were first described long before his time. The only original observations are, in fact, a couple of exceptional clinical cases that he might have come across or heard of during his years, and the theories extrapolated from them were farfetched and clinically unconfirmed (Yanoff & Ducker, 2004, 2008).

13. A maximalist evaluation of the physics of "The Theory of Colours"

What remains from Goethe's theory of colors from the perspective of modern physics and physiology? For one thing, there is the accuracy of his observations. "Goethe had a passion for careful observation abd accurate reporting that may come as a surprise from a theatrical director and famous author of fiction." (Judd, 1970). Second, there is a very attentive description of prismatic colors, for instance, the "disappearance" of the blue and yellow bands in the distant spectrum (far away from the prism). Duck conjectured that Goethe anticipated the Bezold-Bruecke effect (Duck, 1987, 1988), but, in fact, the correct explanation involves the properties of fovea, and the physical phenomenon can be fully explained using Newtonian optics (Treisman, 1996). However, Duck's remark that Goethe explained the formation of several colors better than Newton remains correct (Duck, 1997). The perception of color and the modification of the spectral sensitivity of the eye at extremely low illuminations was quantitatively studied later by several researchers, such as Grigorovici and Aricescu–Savopol (1958). The importance of complementary colors in color perception has been stressed by Land, who proposed the "retinex theory of vision" (Land, 1977). "It is widely used in computer vision, but it does not accurately models human color perception" (https://en.wikipedia.org/wiki/Edwin_H._Land).

The Goethean theory often turns out to be remarkable, when we try to read his comments from a modern perspective. "**The eye may be said to owe its existence to light**", Goethe claims in his Introduction to the didactic part. This can be considered, from a maximalist point of view, to be an understanding of the interdependent development of eye properties and light properties, in the entire evolution of this organ, from Paleozoic creatures to the man (Fernald, 1997).

Finally, the primordial phenomenon (urphänomen) of optics, which might be, for Goethe, the scattering of light on "turbid media",[3] could be understood as the scattering of light in a medium with an arbitrary refraction index. In the language of theoretical physics, this means that the propagation of light is governed by the wave equations for the electric and magnetic components of the electromagnetic field, considered in a spatial domain of arbitrary refraction index.

This approach was worked out by Sommerfeld, Debye and Mie over two decades before and after 1900. Under certain conditions, such equations are equivalent to the Schroedinger equation for the wave function of a quantum particle, supporting the dual—ondulatory and corpuscular—character of light. One of the courses of optics addressed by Radu Grigorovici in the early 1950s is based on the idea that the scattering of light on inhomogeneous media can be used as a key principle in teaching optics. Of course, there is a very great distance between Goethe's qualitative suppositions and this quantitative treatment, but they are not divergent.

While evaluating *Zur Farbenlehre*, as opposed to "The New Theory", we must take into account the fact that while Goethe's study of colors originated in his contact with art milieus, Newton's originated in his will to apply optics approaches similar to those used by Galileo and Kepler in mechanics (Heisenberg, 1974). Goethe speaks to both physicists and humanists, and not only to them but also to mathematicians, chemists, etc. Therefore, the dissatisfaction of physicists can be compensated for, at least in part, by the enthusiasm of the complementary part of the audience. However, the evaluation of *Zur Farbenlehre* from a perspective external both to physics and physiology is beyond the scope of this study.

14. Epilogue

Goethe conducted experiments in the last 40 years of his life; while he claims that "nothing can actually be proved by experiments" and declares that, in his time, he is the only person who knew the truth about the difficult science of colors. However, is this triple paradox that haunts "the Goethean physics" really surprising?

Goethe thinks in polarities and is made up of polarities. His life is a mosaic of polarities, two of them being his anti-Newtonian pertinacity and his humanist Olympian serenity. Goethe is a philosopher without an organ for philosophy, whose opinion about Kant is the first quoted by Cassirer; the reconciler who causes chain suicides; the anti-volcanist who provokes the last eruption of the medieval occultism; the reckless lover who leaves Friederike and courts Ulrike; the Don Quijotean inquisitor of the pantheist religion, ridiculed by the heretics who he fails to punish (Young, for instance); a mixture of wisdom and recklessness, "foolish like a Greek God," in Noica's words. Through his theory of colors, Goethe proves to be both inconsistent and profound, and, in this way, he stays true to himself.

Goethe is defeated by Newton, just like the Greek Gods were defeated by monotheism. He is defeated, but not crushed; what is left is rich enough to reveal a fascinating facet of his genius.

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Cover image
Source: von Goethe (1840).

Notes

1. We shall use, in our discussion, the English translation of this work, due to Charles Lock Eastlake, "an English painter, gallery director, collector and writer of the early 19th century" He prepared an excellent critical apparatus of this edition, being praised enthusiastically by Schopenhauer, in a way quite unflattering for Goethe: "Eastlake, the painter and gallery inspector, furnished his countrymen, in 1840, with such an excellent translation of Goethe's theory of color that it is a perfect

reproduction of the original and reads more easily; in fact, it is understood more easily than the original" (see von Goethe, 1840) Willing to avoid, as much as we can, the repetition of the remarks and comments made by other authors, we shall touch only on a few aspects of the "didactic" part, relevant for our study.

2. We mentioned in Sec. 2 that the connection between light and colors, made in Newton's "New theory", was one of the great virtues of this paper.
3. Although the urphänomen of optics is initially defined, by Goethe, as the light—darkness polarity, this definition is quite flexible. Goethe considers turbidity as a "soft" kind of darkness, so he identifies sometimes the urphänomen with scattering of light on turbid media.

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