Holistic Science Journal
the quest for perception in lived experience

thefieldcentre
JOURNAL OF RESEARCH AND PRACTICE

Goethe's Farbenlehre from the Perspective of Modern Physics

/ Johannes Grebe-Ellis & Oliver Passon

In Dialogue, vol. 1 September 2020 pp. 50-59 (Article)

Goethe's Farbenlehre from the Perspective of Modern Physics

/ Johannes Grebe-Ellis & Oliver Passon[1]

1. Introduction

"Of mine, they can destroy nothing", writes Goethe of the opponents of his *Farbenlehre* in his *Scientific Notebooks*; "for I have built nothing; rather I have sown, and so wide in the world that they cannot taint the seeds."[2] How does it stand today—roughly 200 years later—regarding Goethe's "optical seeds"? The influence of his colour studies on the development of technical, artistic and scientific aspects of colour research to the present day is undeniable. How does it stand, however, with his physical contributions to colour research? Instructive is the shift in the assessment of Goethe's scientific studies and the "seeds of thought" sowed within them brought about by Hermann von Helmholtz in the second half of the nineteenth century. In his 1892 lecture "Goethe's Premonition of Future Scientific Ideas", Helmholtz revised his judgment from 1853 that the *Farbenlehre* was a "failure", and, with a comparison with Faraday and Kirchhoff, gave Goethe a place in the community of physicists.[3] The case of "Goethe contra Newton" has since aroused much emotion; there is hardly a scientific controversy about which more has been written. The efforts of notable twentieth century physicists towards a recognition of Goethe as a pioneer of an holistic view of nature does not, however, change the fact that, from the perspective of physics, the *Farbenlehre* was considered a settled matter.[4]

---

1. Originally published in a slightly different form in B. Steingießer, ed., *Taten des Lichts: Mack & Goethe* (Berlin: Hatje Cantz, 2018), exhibition catalogue. The footnotes have been reduced for this publication and German literature has been cited in English translation, where available.

2. *Ältere Einleitung* (Older Introduction), written probably early 1815 and published in the *Scientific Notebooks*. See J. W. v. Goethe, *Naturwissenschaftliche Hefte*, ed. D. Kuhn (Weimar: Böhlaus Nachfolger, 1962), 182.

3. H. v. Helmholtz, "Über Goethes naturwissenschaftliche Arbeiten", in Helmholtz, *Vorträge und Reden*, vol. 1 (Braunschweig: Vieweg, 1896), 1–40 (lecture to the German Society in Königsberg in 1853). Helmholtz, "Goethes Vorahnungen kommender naturwissenschaftlicher Ideen", in Helmholtz, *Vorträge und* Reden, vol. 2, 335–361 (lecture to the Goethe Society in Weimar in 1892).

4. See, e.g., C. F. v. Weizsäcker, "Goethe and Modern Science", in *Goethe and the Sciences: A Reappraisal*, ed F. Amrine, F. Zucker, and H. Wheeler (Dortrecht: Reidel, 1987), 115-32.

This consensus has been called into question in the last few years by new historical, philosophical and experimental investigations. Against the backdrop of a few remarks on the problematic reception of the *Farbenlehre* and the status of historical and philosophical research on it, the following presents the results of experimental research done over the last decade that have led to a new assessment of Goethe's contributions to physics in the *Farbenlehre*.[5]

2. Newton, Goethe - Who is Right?

Whoever takes up the topic of Goethe's *Farbenlehre* realizes that it is nearly impossible to speak on the strictly physical part of the *Farbenlehre* without at the same time taking a position on the "Goethe contra Newton" controversy. The question "Who is right?" is valid. It has a long tradition and ultimately goes back to Goethe himself, who initiated it with his polemic against Newton's *Opticks*, which he later came to regret. On the other hand, the history of the *Farbenlehre's* reception shows that an undue emphasis on this question leads to an *impasse*. From a modern perspective, the suspicion arises that the debate on the *Farbenlehre* and its relevance for physical optics has gone astray because it has remained limited to three positions: 1) "pro Newton", mainly advocated by physicists, 2) "pro Goethe", mainly advocated by philosophers, and 3) "both are right", advocated by philosophically inclined physicists, such as Werner Heisenberg, or Carl Friedrich von Weizsäcker, who attempted to "save" Goethe by advocating the thesis that the *Farbenlehre* presents a purely subjective, aesthetic view of reality, which can be granted its own domain of validity that is independent of the objective, physical reality described in Newton's *Opticks*.

If one studies the argumentation of the enumerated positions, one comes to the surprising result that the philosopher of science in Berlin, Olaf Müller, emphasizes in the following claim: Goethe's *Farbenlehre* has only been thoroughly studied by a few people, Goethe's discovery of the symmetry of spectral phenomena has been overlooked, and serious experimentation to investigate the complementarity of inverse optical spectra has not been carried out.[6] A few months before his death, Goethe informed Eckermann that his *Farbenlehre* "is very hard to communicate, [...] for, as you know, it requires not

5. Sections of this article have already been published in the following articles: J. Grebe-Ellis, "Goethes Farbenlehre im Lichte neuer Experimente zur Symmetrie spektraler Phänomene", in Über *Goethes Naturwissenschaft*, ed. G. Böhme (Bielefeld: Aisthesis Verlag, 2017), 39-58; M. Rang, O. Passon and J. Grebe-Ellis, "Optische Komplementarität: Experimente zur Symmetrie spektraler Phänomene", *Physik Journal* 16, no. 3 (2017): 43–49; M. Rang and J. Grebe-Ellis, "Power Area Density in Inverse Spectra", *Journal for General Philosophy of Science* 49 (2018): 515–523.

6. O. Müller, *Mehr Licht: Goethe mit Newton im Streit um die Farben* (München: Fischer, 2015). Goethe was already aware of the relation of complementary colour pairs from his research on *coloured after-images* (successive contrast) and the phenomenon of *coloured shadows* (simultaneous contrast). In this context, he spoke of "opposing" (*entgegengesetzt*) and "mutually demanding" (*wechselweise fordernd*) colours and characterized the relationship between a colour and its opposite colour (*Gegenfarbe*) as a "totality" (See *Didactic Part*, §§48–80). In connection with his key insight ("prismatic aperçu") in May 1791, described at the end of the *Historical Part* of the *Farbenlehre* in the chapter "Confessions of the Author", Goethe discovered that the principle of "complementary colours" can also be found in the context of "prismatic colours" (See *Didactic Part*, §§195–247, 309–40). In this regard, note also the systematic nature of Goethe's subjective and objective experiments with optical contrasts in the second section of the *Didactic Part*, "Physical Colours", as well as their summary in the fourth section, "General Introspective Observations". In a supplement to the *Farbenlehre* published in the *Scientific Notebooks*, Goethe summarizes under the title *Complementary Colours* (*Komplementare Farben*) that "just like light and darkness, colours too immediately demand their opposite, so that, namely in thesis and antithesis, all are always contained. Therefore, the demanded colour has been called *complementary*" (*Naturwissenschaftliche Hefte*, 190).

only to be read and studied, but to be *done*, and this is difficult".[7] None of the physicists mentioned have heeded Goethe's request to not only study it theoretically, but also to test it experimentally—a request that Goethe was justified in making, seeing that he himself had fulfilled it with respect to Newton's *Opticks* by carrying out countless experiments in his forty years of involvement in colour research.

The question of which results are obtained by attempting to define Goethe's argument for symmetry more precisely and investigate it experimentally not only provides an escape from the *impasse* described above, it also leads into an area of research, which, by drawing on Goethe's research method, has led to a series of investigations in the last decade that can be understood as contributions to an optical image based, or phenomenological, exploration of optical phenomena.[8] To this area of research belong also the experimental developments which will be described below.

3. Goethe's Method in the Context of his Time

"Goethe's colour research can hardly be understood from the perspective of history of science if it is not taken seriously as a whole and placed in the context of its time." In a study from 2016, "Goethe and the Colour Research of his Time", Friedrich Steinle, an historian of science in Berlin, points out the astonishing fact that so far hardly anyone has taken seriously Goethe's aspiration to contribute to the science of his time with this *Farbenlehre*. "To this day," remarks Steinle, "we are lacking a picture of how Goethe's *Farbenlehre* from 1810 should be evaluated in the context of contemporary colour research".[9]

On the basis of an investigation over many years into the status of colour research at the end of the eighteenth century, Steinle comes to the conclusion that Goethe's work in the field of colour appears "in no way as an exotic undertaking," but rather "is situated squarely within the research questions of its time". Steinle shows that Goethe had taken up the most important strands of contemporary research, and convincingly and successfully developed a number of them further. It would appear that Goethe, when conceiving his *Farbenlehre*, was aiming at nothing less than an attempt to bring the technical and artistic practical knowledge, as well as the extensive scientific colour research of his time, "under an encompassing approach that unified all the individual areas under a single principle. In view of this primary goal, the polemical dispute with the dominant physical theories of light and colour was of secondary importance; a means to an end".[10] To bring colour in its relation to the eye, colour as the result of physical conditions, and colour as the property of bodies "under a common principle, which is most prominently expressed in the colour circle, was his central intention—far more important than the polemic" (see fig. 1).[11]

---

7. J. P. Eckermann, *Conversions of Goethe with Eckerman and Soret*, vol. 2, trans. J. Oxenford (Cornhill, 1850), 410 (conversation with Eckermann on December 21, 1831).

8. See, e.g., the contributions to phenomenological optics in the book series Phänomenologie in der Naturwissenschaft (Berlin: Logos), whose program draws upon, among others, Gernot Böhme's concept of "phenomenology of nature". See G. Böhme, "Is Goethe's Theory of Colour Science", in Amrine, *Goethe and the Sciences*, 147-73. See further the optical image based writings of G. Maier, which explicitly build on R. Steiner's Goethe studies, in *An Optics of Visual Experience* (Edinburgh: Floris Books, 2011).

9. F. Steinle, "Goethe und die Farbenforschung seiner Zeit", in *Die Farben der Klassik*, ed. M. Dönike, J. Müller-Tamm, and F. Steinle (Göttingen: Wallstein Verlag, 2016), 255–289.

10. In an investigation of the structure of the *Didactic Part* of the *Farbenlehre*, Kühl and Rang have shown that the order of the six sections is not arbitrarily chosen, but rather follows a compositional principle that Schiller called a "model for scientific research" in a letter to Goethe. The structure can be understood as a general program for an interdisciplinary and multiperspectival approach to scientific research. See Kühl and Rang's article "A Model for Scientific Research", pp. 60–71 in this issue.

11. These topics are addressed in turn in the first four sections of the *Didactic Part*.

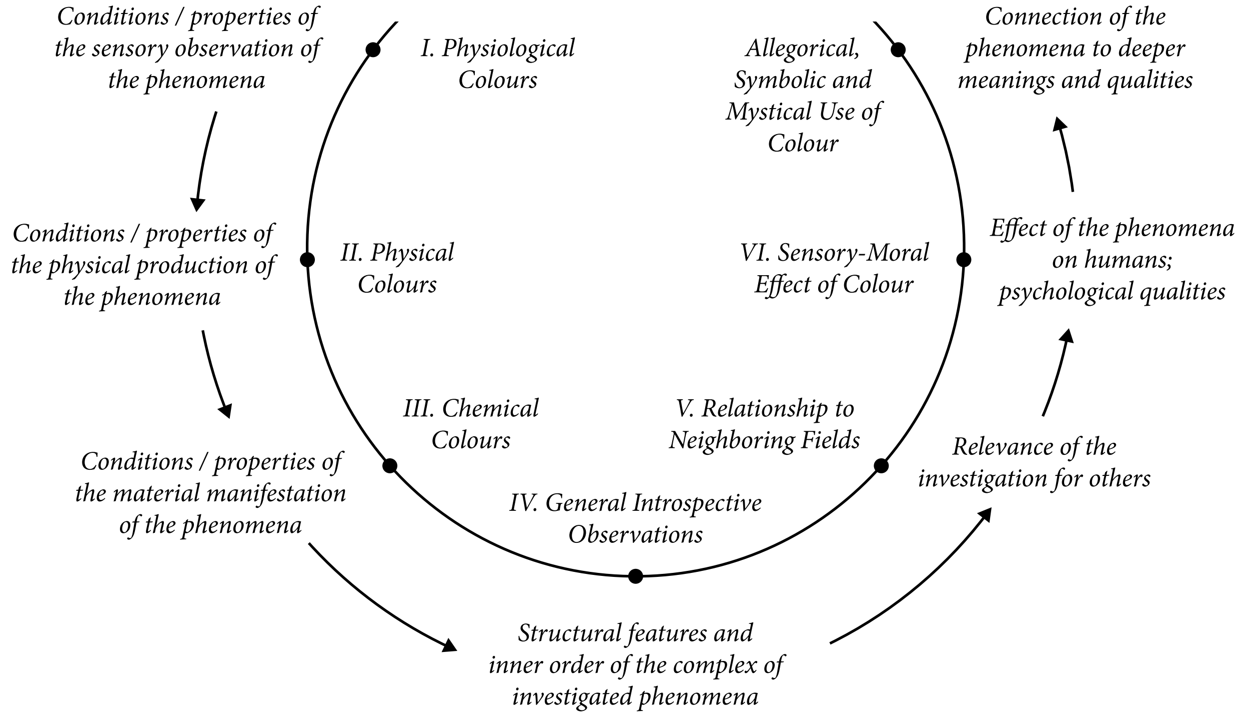


Fig. 1: The structure of the *Didactic Part* of the *Farbenlehre* as an outline of a genetic, multiperspective approach to research. *Inner circle*: The six sections of the *Didactic Part* with the addition of Rang and Kühl's suggested section "Allegorical, Symbolic and Mystical Use of Colour". *Outer circle*: Generalized formulation of the respective research perspective based on Kühl and Rang's "A Model for Scientific Research", pp. 60–71 in this issue.

A further aspect of Goethe's scientific research, which, although it has been partly investigated, has so far scarcely been viewed in an historical context, is his own research *method*. In connection with his chromatic studies, Goethe develops his own reflections on phenomena, theories, and experimentation, i.e., on the way that theoretical conclusions are drawn from observation and experimentation. The methodological writings which appear in this context show that he had greater concerns than critically reflecting on his own methodology and demarcating it from Newton's. They present an outline of a general method of experimental research, which contains considerations that are still relevant today for the conditions and possibility for acquiring knowledge based on experimental data.[12]

How these philosophical reflections of Goethe's relate to his own scientific practice and fit into the historical context of the French enlightenment has been investigated by Steinle in a comprehensive study, "'Experience of a Higher Kind': Goethe, Experimental Method and the French Enlightenment".[13] On the basis of the key mythological text, "The Experiment as Mediator between Object and Subject", Steinle reconstructs Goethe's epistemological critique of single experiments and sketches a method of "manifolding" (*Vermannigfaltigung*) the experiments through systematic variation of the parameters in the experimental setup. "According to Goethe's general thesis, the basis for theorizing first appears in the form of a

12. Beside dispersed methodological remarks in the "Contributions to Optics" from 1791-2 and in the *Farbenlehre* from 1810, two essays in particular are worth mentioning as key philosophical texts: "The Experiment As Mediator Between Object and Subject", in Goethe, *Scientific Studies*, ed. and trans. D. Miller (New Jersey: Princeton University Press, 1995), 11-7, and "Empirical Observation and Science", in Goethe, *Scientific Studies*, 24-5. For Goethe's conception of science see also R. Steiner, *Nature's Open Secret: Introductions to Goethe's Scientific Writings*, trans. J. Barnes and M. Spiegler (Hudson, NY: Anthroposophic Press, 2000), especially the chapter "Goethe As Thinker and Researcher", 166-91.

13. F. Steinle, "'Erfahrung der höhern Art': Goethe, die experimentelle Methode und die französische Aufklärung", in *Heikle Balancen: Die Weimarer Klassik im Prozess der Moderne*, ed T. Valk (Göttingen: Wallstein Verlag, 2014), 221– 249. See further F. Steinle, "'Das Nächste ans Nächste reihen': Goethe, Newton und das Experiment", *Philosophia Naturalis* 39 (2002): 141–172.

series of experiments adjacent to one another." For only *varying* the individual observations allows the functional relations of an observational context to become visible. This leads, following the example of "mathematical method", to a kind of experience composed of many others and which Goethe therefore called an "experience of a *higher* kind".[14] Only this "experience of a higher kind", which Goethe sometimes referred to as a "pure phenomenon", or "archetypal phenomenon", can present the basis of empirical rules and generalizing conclusions. By drawing a connection to the French Encyclopedists d'Alembert and Diderot, Steinle was able to show that Goethe's methodological considerations are "in no way as exotic as sometimes presented".[15] Regarding considerations of this kind, the question of whether there were, in addition to the connection to editors of the *Encyclopédie*, other parallels or possible exemplars cannot be conclusively answered at present. However, it is already "clear that Goethe, with his reflections on experimental practice and reasoning, was employing a practice that is encountered far more widely in science than has been assumed so far and therefore deserves a prominent place in a yet to be written history of the philosophy of the experiment".

4. New Experiments Confirm the Symmetry of Spectral Phenomena

Against the background achieved by looking at new historical and philosophical investigations of Goethe's *Farbenlehre*, we will return to the question raised at the beginning of this article of how the "optical seeds" stand today from the perspective of modern physics. The answer is given by experimental developments which have been elaborated in the last ten years by the physicist Matthias Rang.[16] They relate to Goethe's investigations in the second section of the *Didactic Part*, i.e., to the more strictly physical part of the *Farbenlehre*, which was the most important part for Goethe—and which also suffered the harshest rejection by physicists. Using technical optics, Rang shows how the unity of the complementary spectral phenomena, which was discovered by Goethe but remained neglected in optics, can be framed in terms of physics and demonstrated to be a fundamental condition of these phenomena.

The results of Rang's experiments can be summarized as follows: Goethe discovered *complementarity* as a symmetrical property of spectral phenomena. According to modern

---

14. In the aforementioned essay "The Experiment As Mediator Between Object and Subject", one finds, among others, the statement: "From the mathematician we must learn the meticulous care required to connect things in unbroken succession, or rather, to derive things step by step. Even where we do not venture to apply mathematics we must always work as though we had to satisfy the strictest of geometricians. In the *mathematical method* we find an approach which by its deliberate and pure nature instantly exposes every leap in an assertion." Goethe, *Scientific Studies*, 16 (emphasis added). See further the section "Relationship to Mathematics" in the *Didactic Part*, §§722-29.

15. In the text from the archive "On Mathematics and its Abuse" (1826) Goethe quotes d'Alembert from the *Encyclopédie* and thus he himself gives an indication of the methodical parallels between his method of "manifolding" (*Vermannigfaltigung*) and mathematics. See further Steiner's footnote to the d'Alembert quote: "What the first proposition is in mathematics, is, for Goethe, an experience of a higher kind in science. Also, the way that d'Alembert thinks of this manifolding of the proposition is completely analog to what Goethe says about the relation between experience of a higher kind and normal empirical experience." Goethe, *Naturwissenschaftliche Schriften*, vol. 2, ed. R. Steiner, 4th ed. (Dornach: Rudolf Steiner Verlag, 1982), 47 (photomechanical reprint of the original Kürschner edition of Goethe's work (1883-1897).

16. M. Rang, *Phänomenologie komplementärer Spektren* (Berlin: Logos, 2015); M. Rang and J. Grebe-Ellis, "Komplementäre Spektren: Experimente mit einer Spiegel-Spalt-Blende", *Mathematisch Naturwissenschaftlicher Unterricht (MNU)* 62, no. 4 (2009): 227–231; M. Rang, O. Passon, and J. Grebe-Ellis, J. (2017): "Optische Komplementarität. Experimente zur Symmetrie spektraler Phänomene", *Physik Journal* 16, no. 3 (2017): 43–49.

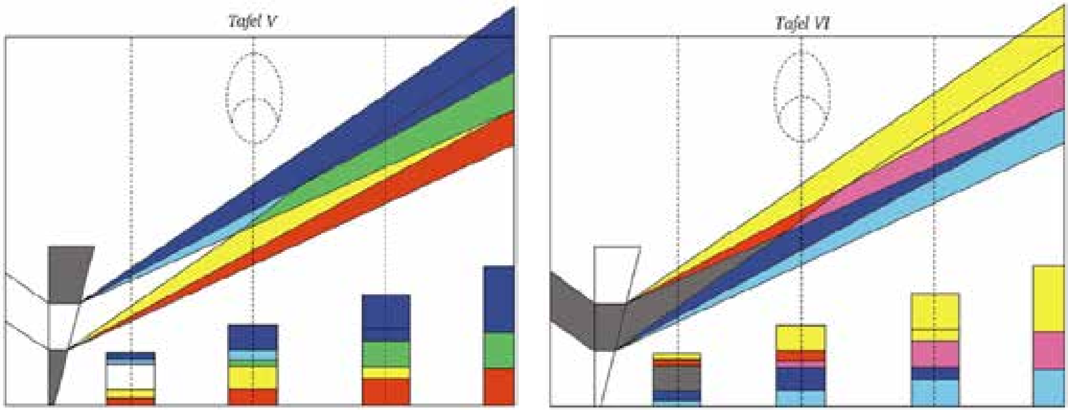


Fig. 2: Goethe's representation of the formation of complementary complete spectra by successive overlapping of complementary edge spectra as a function of the distance from prism. *Left*: slit spectrum. *Right*: the complementary case of the bar spectrum in which the slit is replaced by a bar, i.e., the light rays in a dark environment are replaced by a shadow in a light environment.

physics, complementary and inverse spectral states result from the conservation of energy of the optical system. Complementary spectra arise simultaneously at a mirror slit aperture and are dependent on each other functionally, like the transmission and reflection of a filter. The relevant experiments represent symmetrical extensions and generalizations of Newton's experiments.

How did Goethe arrive at the idea of the symmetry of spectral phenomena? He searched for the *observable conditions* for the appearance of colour. The most fundamental of these conditions appeared to him to be that colour only appears at optical contrasts, i.e., at boundaries of light and dark. By systematically varying and inverting these *contrast conditions*, Goethe arrived at the realization that producing images by passing inverse optical contrasts through a prism always results in isomorphic, complementary spectra.

Against the background of the presentation that he found in Newton's *Opticks*, this was an unexpected discovery. In light of the symmetrical conditions of appearance it seemed only consistent to Goethe to see the complementary spectrum as the equal counterpart to Newton's spectrum and to emphasize that the spectra belong together (fig. 2). And it is immediately understandable why Goethe could also see in the organizational schema of the colour circle an adequate representation of the lawfulness he found with respect to the complementarity and mixing of colour.

It seemed obvious to Goethe to expect a theory of spectral phenomena to take into account the symmetry that the phenomena show. Because of this he insisted on the observation that, for colour to arise, an interaction of light and darkness is always necessary. Newton's limitation to the slit spectrum awoke in him the impression of an arbitrary interference with the empirical data that resulted in the suppression of a whole class of phenomena and therewith a structural feature of spectral phenomena, which could be observed in other areas, such as atmospheric and polarization colour and therefore seemed of general significance.

Goethe could only provide qualitative and rudimentary experimental verification of optical complementarity as a symmetrical property of spectral phenomena. Nevertheless, with his experimentation and presentation of the arising of colour at inverse optical contrasts, Goethe sketched the methodological path which should, in principle, lead to such verification. It was the Norwegian André Bjerke who, in the 1950s, made the symmetrizing of spectral phenomena by systematic inversion, i.e., the interchange of light

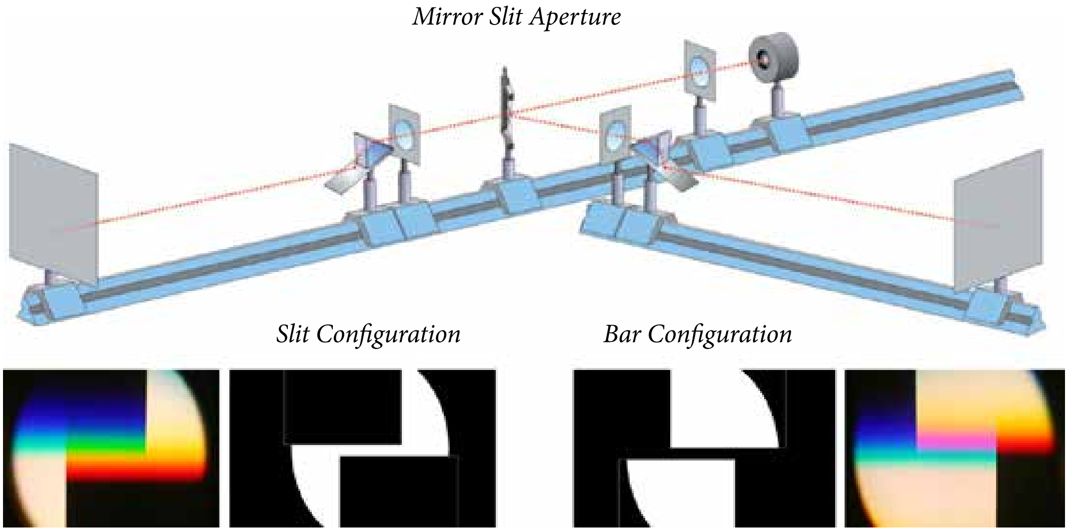


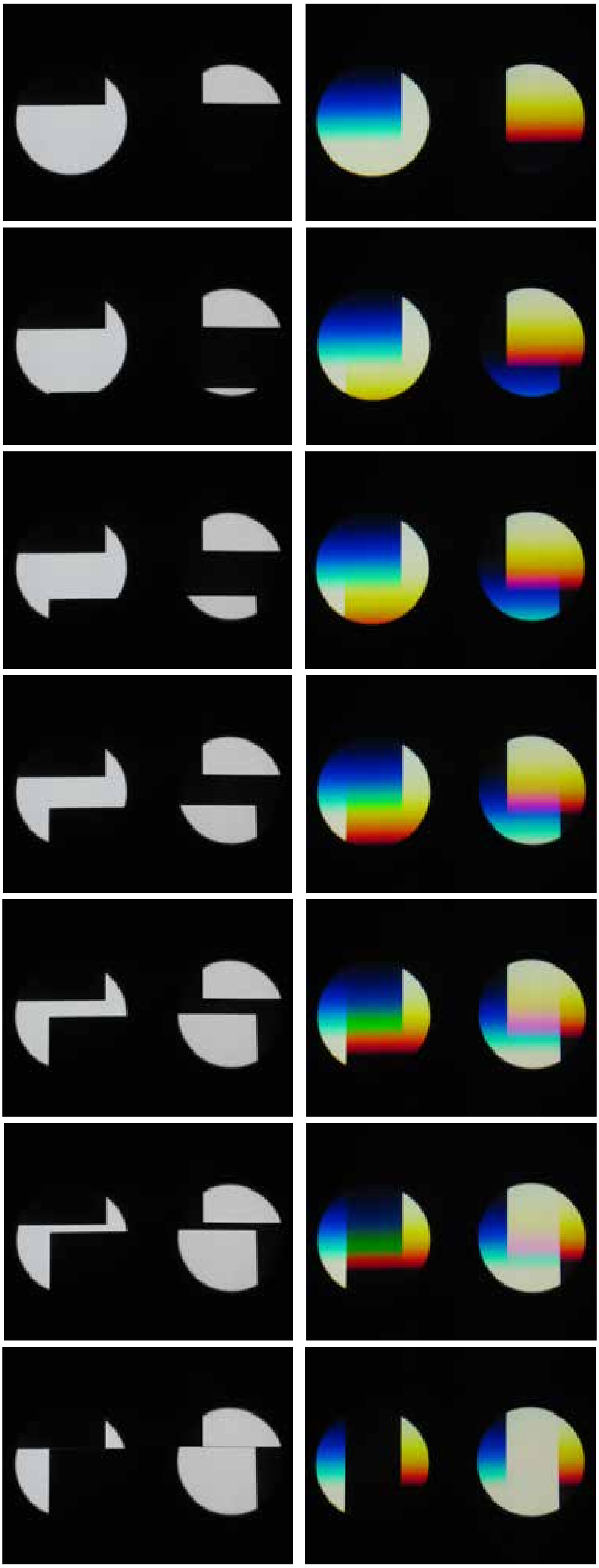
Fig. 3: Simultaneous production of complementary spectra using a mirror slit aperture. The optical transmission path (*left*) and reflection path (*right*) are constructed such that they are reflectionally symmetrical with respect to the plane of the mirror aperture. Without the prism, the mirror aperture appears as a *slit* in the transmission path and as a *bar* in the reflection path. Photos: M. Rang

and darkness in the most important of Newton's experiments, into a research program.[17] The decisive breakthrough that led to the success of this program was first made by Matthias Rang, who built on Torger Holtsmark's work with the introduction of a mirror slit aperture and the concept of an optical "lightroom" (figs. 3, 4 and 5).

On this basis, Rang was able to show in the last few years that, in principle, all of Newton's experiments can be inverted in the sense of Goethe's idea of polarity; the optical complementarity, as a property of chromatic phenomena that are produced with a strictly inverse setup, is preserved when the energy in the optical system under observation is conserved. In particular, this is also valid for the various versions of the *experimentum crucis*, an experiment that Newton conceived to prove the purity of spectral colours and essentially consists of two consecutively placed prisms (fig. 5 shows a variant of this experiment). Rang concludes that this results in a generalization of the concept of monochromaticity that relates the behavior of a selected spectral area, when tested for

17. With his suggestion of constructing a *mechanical* inversion of Newton's fundamental experiment, Goethe was able to give a perspicuous presentation of his discovery of the symmetry of complementary spectra. From a modern perspective, however, the impression arises that with this example of inversion Goethe also helped foster an uncomplete, mechanical understanding of inversion. In the twentieth century, this resulted in a tradition of attempts at inversion that were to remain ineffective so long as it was not recognized that the problem of inversion can be solved, in principle, not mechanically, but *optically*. It is nevertheless worth mentioning the work of Kirschmann, who, in 1917, was the first to show that the inverted spectrum can in principle be used spectroscopically in the same way as the slit spectrum. See A. Kirschmann, "Das umgekehrte Spektrum und seine Komplementärverhältnisse", *Physikalische Zeitschrift* 18 (1917): 195–205; Kirschmann, "Das umgekehrte Spektrum und die Spektralanalyse", *Zeitschrift für Instrumentenkunde* 44 (1924): 173–5. Significant preliminary work on overcoming the mechanical picture of inversion was carried out towards the end of the 1950s by Bjerke's research group in Olso; see A. Bjerke, *Neue Beiträge zu Goethes Farbenlehre* (Stuttgart: Freies Geistesleben, 1961). This led to Holtsmark's suggestion for the generalization of the *experimentum crucis*, which was realized experimentally by Sällström at the end of the 70s; see T. Holtsmark, "Newton's Experimentum Crucis reconsidered", *American Journal of Physics* 38, no. 10 (1970): 1229–1235; Holtsmark, *Colour and Image: Phenomenology of Visual Experience*, ed. J. Grebe-Ellis (Berlin: Logos, 2012); P. Sälllström, *Monochromatic Shadow Rays*, ed. J. Grebe-Ellis (Drucktuell: Gerlingen, 2010), DVD.

Fig. 4: Phases of the simultaneously produced complementary spectra of a high pressure xenon lamp with decreasing aperture. The left column shows the aperture; the right the corresponding spectra. Photos: J. Grebe-Ellis and Sebastian Hümbert-Schnurr



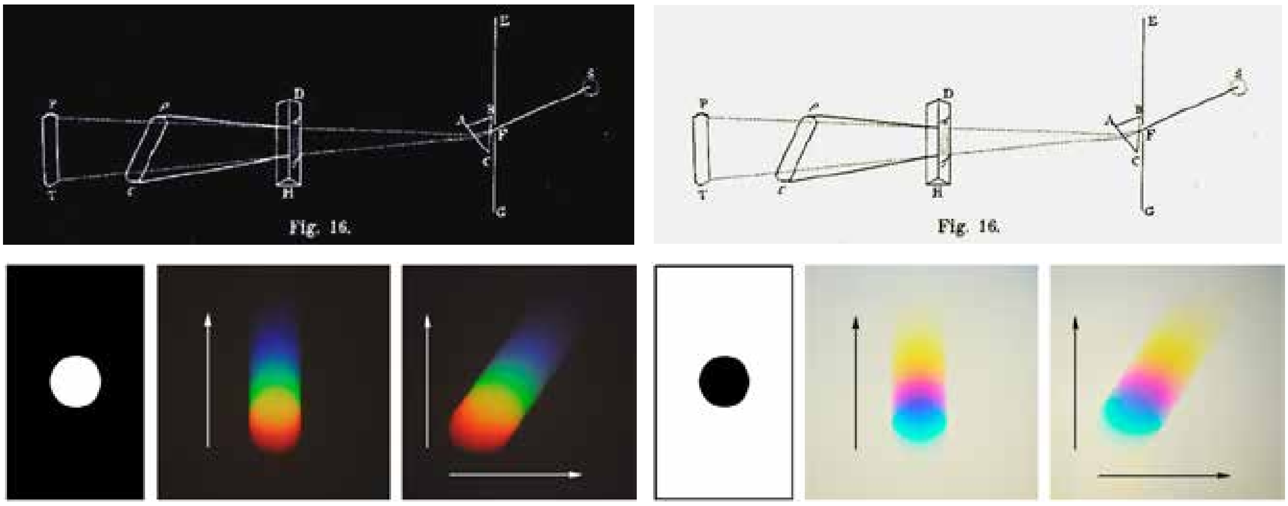


Fig. 5: Newton's *experimentum crucis* with crossed prisms (*left*) and the inverted version (*right*). Bottom row: The production (*middle*) and analysis (*right*) of the spectrum of a source similar to the sun with a dark background (*left*), together with the complementary spectrum of a "dark sun" with a light background. The arrows indicate the prisms' direction of refraction. Photos: M. Rang

spectral purity, to the context of its production: whether a colour behaves in a spectrally pure manner depends on whether it is *investigated in the environment in which it was produced.*

These results go far beyond the historical context of Goethe's *Farbenlehre*. They result from extended, modified and generalized variants of Newton's experiments and confirm Goethe's results with respect to the importance of the complementarity of spectral phenomena. The symmetry of complementary spectral phenomena is not limited to the region of the strictly optical part of the electromagnetic spectrum, but rather, being a general property of radiation energy, can also be demonstrated for the neighboring ultraviolet (UV) and infrared (IR) spectral regions. This has been done by Rang and Grebe-Ellis, using measurements of the complementary spectra of a high pressure xenon lamp (fig. 6).[18] In light of this research one can speak of ultra-yellow (UY) and infra-cyan (IC) regions of the complementary spectrum that correspond to the UV and IR regions of the normal spectrum. It remains to be seen whether, on the basis of Rang's techniques, spectroscopic applications can be developed that have advantages in specific cases over established methods.

5. Conclusion

This presentation of recent historical, philosophical and physical investigations on Goethe's *Farbenlehre* shows that the image of Goethe as a scientist and colour researcher has been reanimated in recent years. The research on the *Farbenlehre* is in no way finished. On the contrary, the studies presented above clearly show that we are in many ways at the beginning—and that this beginning is promising.

18. M. Rang and J. Grebe-Ellis, "Power Area Density in Inverse Spectra", *Journal for General Philosophy of Science*, 49 (2018): 515–523.

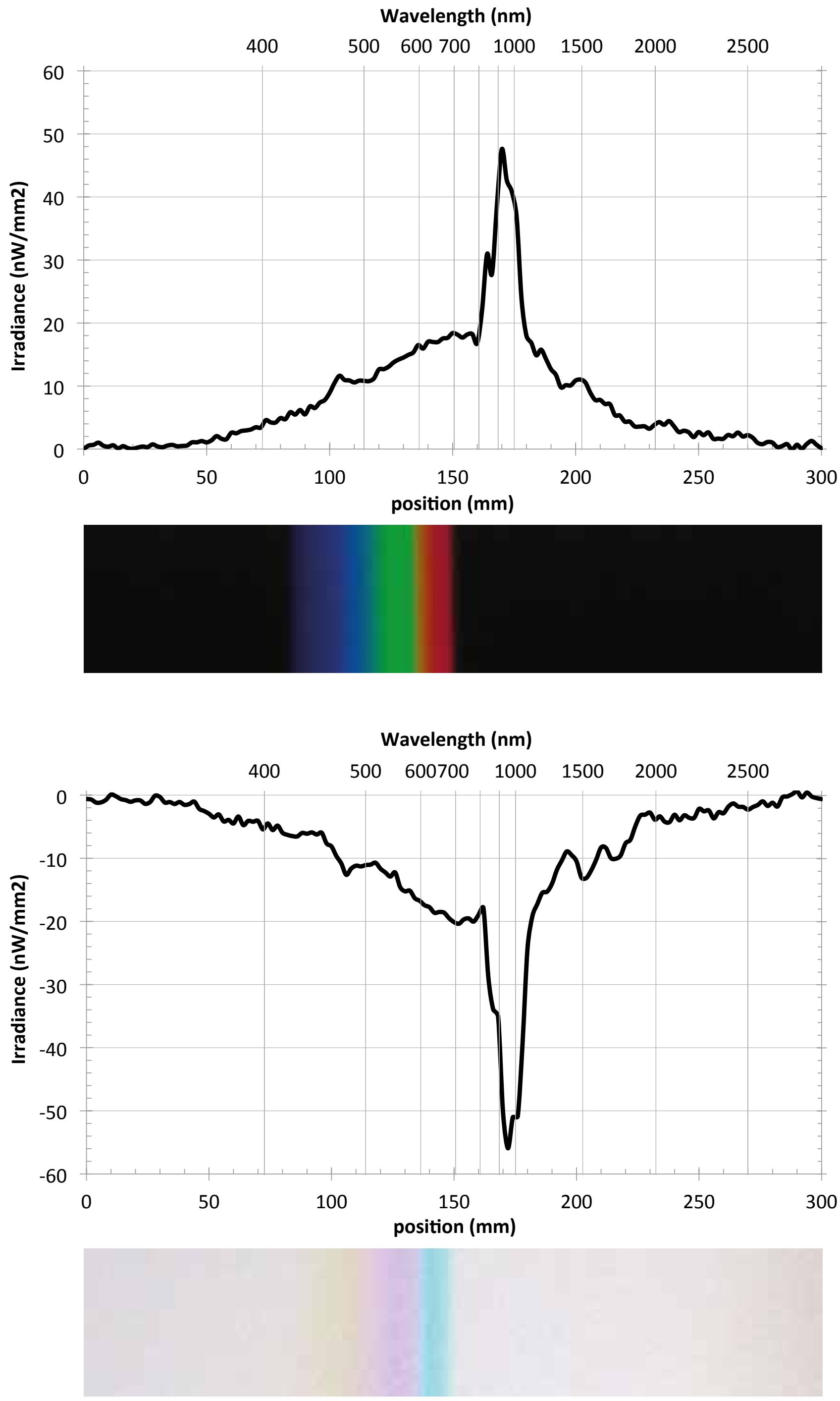


Fig. 6: Intensity of irradiation in the slit spectrum (*top*) and in the complementary bar spectrum (below) of a high pressure xenon lamp.