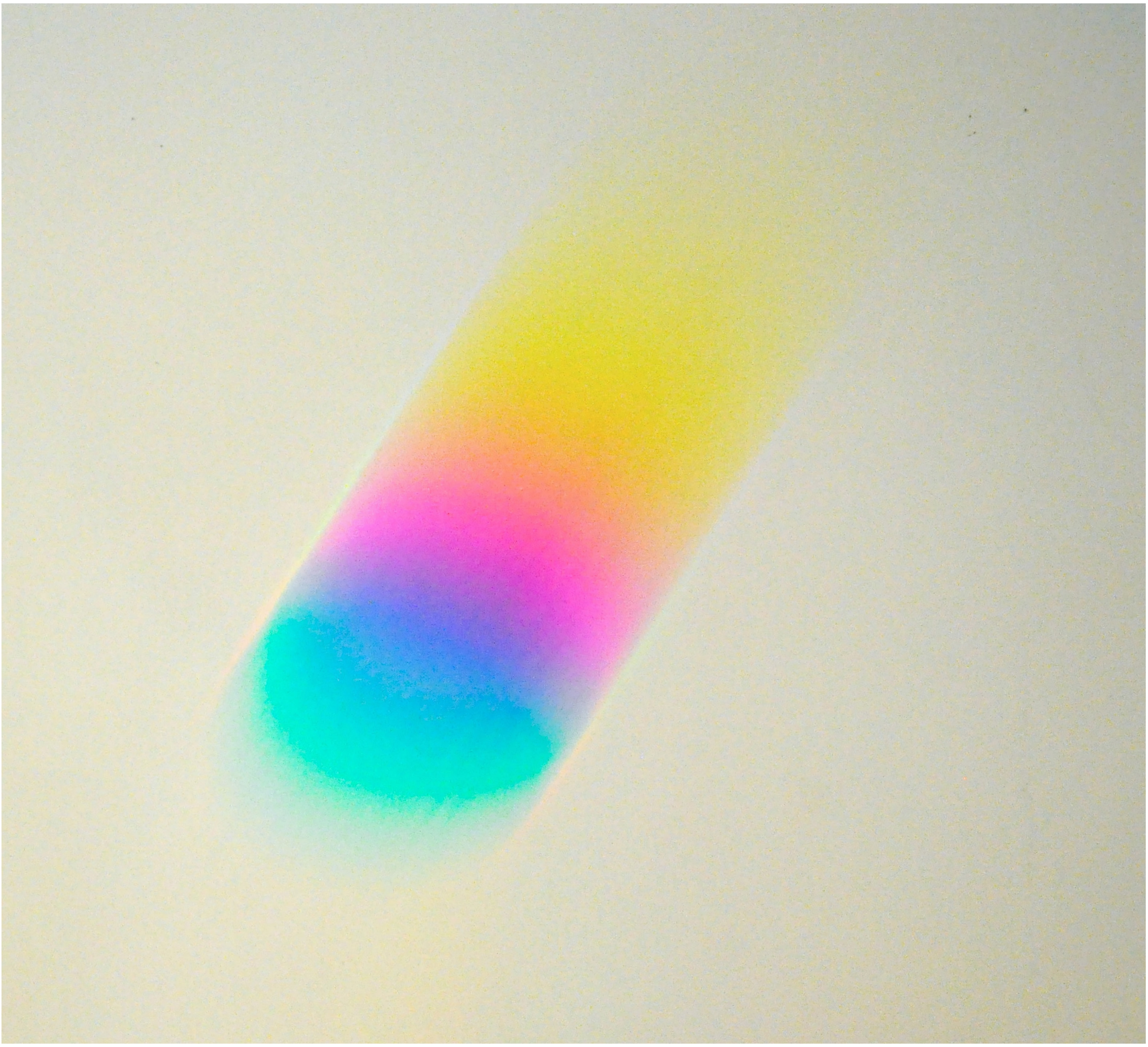

experience COLOUR

experience
COLOUR

An Exhibition by
Nora Löbe & Matthias Rang

Edited by Troy Vine

Sponsor's Foreword

Aonghus Gordon

Founder and Executive Chair of Ruskin Mill Trust

Welcome to this catalogue. It has come about under the auspices of the Field Centre, a research institution for investigating and developing the ideas that underpin Ruskin Mill Trust's educational methods. An important source of inspiration is the scientific writings of the German poet Johann Wolfgang von Goethe and it is therefore significant that our first research publication should be on colour.

It may be said that never before has colour been so universally accessible in both a natural and an artificial context as it is today. The tension between created colour and natural colour has consequences for the observer. It may be that the development of radiant coloured light, experienced for the first time in the cathedrals of north-west Europe, had a cathartic and uplifting effect, contributing to the profound sense of the sacred. Silica glass acted as the medium of transmission, with finely dissolved metallic oxides creating a spectrum of colours. The innovation of radiant colour created through a synthesis of imagination and technology may be appreciated as one of the great achievements of the thirteenth century. This has reappeared in the form of our radiant screens for which, as in the thirteenth century, mass communication was one of the motivations.

Yet what type of light and colour do we experience when looking at the thirteenth century window? Is the quality of the light the same as that of a screen, or intrinsically different? The catalogue of this exhibition is an opportunity to explore not only a wide range of colour phenomena in context, for an engagement with colour itself, but also the perspectives of the academic and the practitioner. The need to participate in a scientific endeavour increases by the day and only by doing so can a marriage of the experiential and the conceptual come about. The separation of percept and concept is one of the Western world's contrivances to maintain the separation within our experience and the inability to create unity. The colour exhibition brings together the experiential and the conceptual side of colour – it grants the participant the power to reassemble experience as potential meaning.

Ruskin Mill Trust is based on a conception of organisational method in working with students and children with special needs that starts from considering the unity before going into specification. In this way, the part may reconfigure back into the whole. Clearly, to experience the colour green in nature is important and deeply renewing: it may provide a sense of equanimity in the troubled soul of the young person. However, to see that green holds the centre ground in the appearance of the rainbow after the departing storm places green back into the context of the whole – experience is now part of a larger unity. This ultimately contributes to a sense of belonging and may transcend to the quality of perceiving the sacred.

I would like to thank Dr Troy Vine for his editorial skill, academic rigour and tireless commitment in bringing this catalogue together. The catalogue is sponsored by the Ruskin Mill Land Trust and Hermes Trust.

Editor's Foreword

Troy Vine

In 2010 I visited the Goetheanum in Switzerland to see an exhibition that was commemorating the bicentennial of Goethe's *Farbenlehre* by recreating a plethora of the colour phenomena described in it. I had recently completed my doctorate in particle physics and was astounded to see that an approach to colour was possible that did not once mention particles. A few months later, the crowning exhibit travelled to Humboldt University in Berlin, with me in its wake. At the conference based around it, I was captivated by the philosophers and historians of science discussing Newton's and Goethe's colour research. It was then that I realized I had finally found the discipline in which I felt at home.

However, I would certainly not have believed then that seven years later I would be contacting those same people asking them to contribute to an exhibition catalogue I was editing for the same exhibition, which was now traveling to England. In the intervening years I settled in Berlin, first learning German and then doing research on Goethe and Wittgenstein at Humboldt University. I soon discovered that there was a thriving community of researchers connected with Humboldt University who were developing ideas from Goethe in many surprising directions.

The intention behind this catalogue was to make some of that research available to the English reader. Not only are the descriptions of the exhibits, now available in English for the first time, embedded within an introduction to colour phenomena, but also a number of essays deal with topics that have so far only appeared in German. This work has been complemented by contributions from renowned English speaking academics and practitioners working with the ideas of Goethe. It is fitting that researchers speaking the language of Newton and researchers speaking the language of Goethe have collaborated on this project.

I would like to thank all the contributors. In particular, I would like to express my gratitude to Nora Löbe and Matthias Rang. Beyond designing an inspiring exhibition and making this field of research visible to its visitors, they have made this field of research understandable to readers of this catalogue by putting the exhibits into context with helpful introductions and descriptions. I am honoured to be able to contribute to this large project in a small way by editing this catalogue.

Designers' Foreword

Nora Löbe & Matthias Rang

Why colour? – We are surrounded by colour in every moment of our lives, yet we barely ever notice it. Usually we only see colour as a medium in which things appear. In daily life it plays a role similar to a film score: it transmits emotional contents and creates atmosphere without which the world would seem colourless, dull and ultimately pointless. In this exhibition we want to expand on the idea of colour performing the function of a carrier and mediator of moods and approach it as a topic in its own right. Here, the works of art, exhibits and experiments become media for colour.

The exhibition was originally developed and displayed at the Goetheanum in Switzerland in 2010 in commemoration of the bicentennial of Johann Wolfgang von Goethe's *Farbenlehre*. Since then, it has been shown at different locations under the title "experiment COLOUR". The title expressed a methodical concept: colour as experiment wants to be a journey of discovery starting from the phenomenon. For the exhibition in Great Britain, which this catalogue accompanies, we have developed the exhibition further and are very happy to present new experiments, especially experiments stemming from the colour researcher Michael Wilson. Wilson's field of research was the perception of colour – though not from a medical or physiological point of view but from the perspective of the perceiver and their experience. Thus, we are very happy to show the expanded exhibition under the new title *experience COLOUR*.

The exhibition is divided into three parts. The first part, *exploring COLOUR*, invites you to discover colour phenomena. You will find interactive experiments similar to a science centre, where you can experience colour phenomena. The second part of the exhibition, *understanding COLOUR*, offers a scientific deepening. Here, we show experiments by Newton, Goethe and Michael Wilson. The third part, *applying COLOUR*, focusses on your own experience. The three parts of the exhibition emphasising exploring, understanding and applying build on one another and mirror the historical process of how new areas of research are usually found and approached.

When an explanation is given before a phenomenon is experienced, the phenomenon becomes simply an illustration of a general law or theory. If the phenomenon is discovered on one's own, it becomes a somewhat uncomfortable, puzzling or exciting motivation to make sense of what is going on. Our exhibition is based on the latter didactical concept: we like to encourage you to act as researchers in our exhibition, exploring a topic of colour in experiments. But of course, this would not work without any guidance. Simple instructions on each exhibit give you enough information to operate the experiment, but more. Once you are fully engaged, you might be interested in the additional explanations, theoretical statements and suggestions for further experimentation that are available on wall panels, in the written exhibition guide and of course in the descriptions in this book.

The presentation of the exhibits is based on the following design concept. The stands for presenting objects and experiments are simple laminated plywood frames open on two sides. The frames are coated in anthracite on the outside, inside they are varnished. The natural wooden design on the inside contrasts with the neutral coloured, uninspiring outside. The two open sides give the stands a spatial orientation that guides you intuitively to the front. The parts of the experiment that are relevant for understanding the phenomena are freely accessible on the outside. Here, you can become active, setting discs into rotation, looking through large lenses and prisms, mixing colours, turning lights on and off and carefully observing. The other parts of the experiment, which are necessary to gain the desired effect but are not the focus of the experiment, are placed inside the open frame – under the table, but not hidden from view. Thus, you can understand how an experiment works without being initially distracted by too many details.

The texts on wall panels and the descriptions in this catalogue are also an important part of the exhibition. When we observe a new phenomenon we often wonder about its meaning, how it arises and how to understand it. The descriptions offer an overview by contextualizing various phenomena and showing not only the variety of phenomena but also their relations within an a particular domain. This is an essential part of understanding the phenomena. In addition, we can interpret or present phenomena within an historical scientific paradigm or the present one. We have limited this approach to a few remarks, but you will find comprehensive essays on this topic in this publication. We hope we have provided an orientation in the field of colour with the following exhibit descriptions and wish you as reader or visitor a stimulating and beautiful experience!

We wish to thank Glasshouse College, Ruskin Mill Trust, their staff and the whole team working on the exhibition, without whom it would not have been possible. Through this collaboration the exhibition comes to Great Britain for the first time and with new exhibits.

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Exhibits and Essays in Bold

Goethe and Ritter

Olaf L. Müller[1]

1 Introduction

Goethe's *Farbenlehre* (1810) is regarded as a Don Quijote adventure. Critics frequently use the "Polemic Part" and its furious attacks on Newton's *Opticks* (1704) to argue for Goethe's incompetence in scientific matters – often, however, without having studied this part of the *Farbenlehre*. Now that it has been translated into English, the text is available to a wider readership – and with it Goethe's coloured plates, some of which had been omitted from previous translations.[2] For this reason alone the new edition cannot be praised enough.[3]

Michael Duck, one of the two translators, claims in the introduction:

> The general consensus has always been that Newton succeeded brilliantly [...] and the scientific world was unanimous in its rejection of *A Theory of Colours* – particularly in Germany.[4]

Duck seems to be unaware that in the German literature this consensus has been challenged.[5] While Duck concentrates on known weak points of Goethe's reasoning, it seems more instructive to ask: Is it possible to defend Goethe's criticism of Newton with modern means? The exhibition displays some spectacular results of the *experimental* work on Goethe's *Farbenlehre*; in my contribution, I will discuss some *theoretical* implications.

Contrary to Duck's claim, scientists in Goethe's day were not unanimous in their rejection. Though about half of the scientific reactions to the *Farbenlehre* were negative, one third of them were in favour and the rest were undecided.

It thus becomes apparent that controversies in the history of science never proceed as linearly as a Whiggish view of history would like to have it. To reach an accurate view of how events unfolded, one is well-advised to also consider what Chang calls complementary science and charitably study the research of those who don't toe the party line.

In order to do this, it does not suffice to rely on historical statements of opinion. Rather, the arguments and experiments have to be scrutinised. As obvious as this may seem, it leads to surprising results, as can be seen, for example, in the case of Johann Wilhelm Ritter (1776–1810), which I will focus on here. Since Ritter was a leading scientist of Goethe's time, his attitude towards Goethe's criticism of Newton is more relevant than that of other scientists who are nowadays forgotten.[8]

The story of the collaboration between Goethe and Ritter is being told here for the first time in English. As I will argue, Ritter knew Goethe's criticism of Newton well. He approved of it and developed it further – with great success: Goethe's ideas led Ritter to discover what is nowadays known as ultraviolet radiation; an epoch-making discovery.

Ritter moved to Jena as a student in 1796. At that point, Goethe had spent several years researching colour; although the publication of the *Farbenlehre* (1810) was still far off, he had already published key ideas about the polarity of prismatic spectra.[9] This will be explored in the next section.

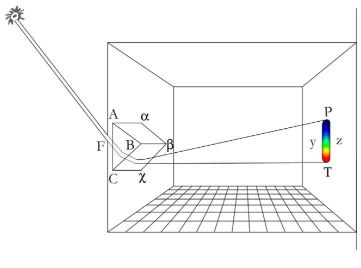

Fig. A: *Newton's discovery – the decomposition of white rays of sunlight (1672)*. A ray of sunlight is sent through the hole, F, into a prism, where it is split into its coloured components. (Colour diagram by Matthias Herder and Ingo Nussbaumer, following a black and white drawing from Newton's lecture notes. See *figure 2* in Newton [UFVo]OM]:3; source: O.M. [ML], colour plate 1.)

2 Goethe's Discovery of a Polarity in Newton's Spectrum

Newton sent a narrow ray of light, in dark surroundings, through a prism (Fig. A), producing his famous spectrum (Fig. B):

blue
turquoise
green
yellow
red.[10]

Newton considered the colours themselves unimportant; he treated them as a *factum brutum* to be accepted without further analysis. Goethe, by contrast, was interested in the colours as colours – and in their relations to each other. He noticed that the cooler colours at one end of the spectrum are the polar opposite of the warmer colours at the other end (Fig. C): If you stare at *one* end of Newton's spectrum for a while and then look at a white surface, you will see the *other* end of the spectrum as an afterimage (Fig. D). Blue and turquoise are the *complementary colours* to yellow and red.[11]

The prismatic colours are thus closely connected to the so-called physiological colours, which are created by the eye and show up, e.g., in experiments involving afterimages. A colour circle in which complements are opposite each other represents the appearance of colour in both domains (Fig. E).

While Newton did not mention the symmetrical structure Goethe and others had discovered within the spectrum (Fig. F and G), the poet managed to demonstrate its far-reaching implications. For example, he produced a complementary counterpart to Newton's spectrum by exposing the whole prism to light and obstructing precisely those rays that passed through the prism in Newton's experiment (Fig. H, I, and J). Goethe invoked an optical polarity to describe the relation between the two experiments: Interchanging the poles of darkness and light leads to an inversion of the colours in the spectra. According to my interpretation, Goethe's overarching aim was to show that such polarities arise in all optical areas and that they result from the general opposition of light and darkness.[12]

Goethe did not always achieve his aim. He failed to produce complementary counterparts to some of Newton's more complicated experiments, e.g. his famous *experimentum crucis*.[13] Goethe claimed he could repeat the experiment with the inverted spectrum and promised to show the experimental setup in a colour plate; unfortunately, the plate never materialised.[14] As we know now, Goethe's plan was bound to fail because the experiment requires a light source that did not exist in his time. Technological progress has, however, given us such a light source. In 2010 Matthias Rang and Johannes Grebe-Ellis performed an experiment that vindicated Goethe's claim.[15]

With this in mind, let us return to Duck's introduction to the *Farbenlehre*:

> It is true that Goethe's theory can be used to give a plausible explanation of some of the more basic colour phenomena Newton studied – such as [...] the spectrum formed when a beam of sunlight is passed through a prism. And, as we have seen, he used not a little ingenuity in some of them. However, most of Newton's more sophisticated experiments [such as the *experimentum crucis* – O.M.], all of which were repeated by Goethe, clearly demonstrate that light is composite and contains within it variously refrangible coloured lights. Goethe vigorously opposed this concept until the end of his life; notwithstanding the fact that he could not find a single physicist to support him. That he was able to continue to do this even after he had absorbed the contents of Newton's *Opticks* had nothing to do with physics.[16]

Two points are surprising in this passage. Firstly, Duck endorses the idea of an experiment *demonstrating* the truth of a theory, despite the fact that for more than a century the idea of proving a theory experimentally has been rejected by philosophers of science.[17] Secondly, Duck claims that Goethe had no support from physicists at all. This is false, as the remaining sections describing the close collaboration between Goethe and Ritter show.

3 Ritter's Galvanic Experiments in Light of Goethe's Idea of Polarity

As we have seen, Ritter first met Goethe when Goethe's research was aiming at the polarity of colours in several areas. As I will show, one conversation was enough to convince him of Goethe's aims, which led to significant discoveries.

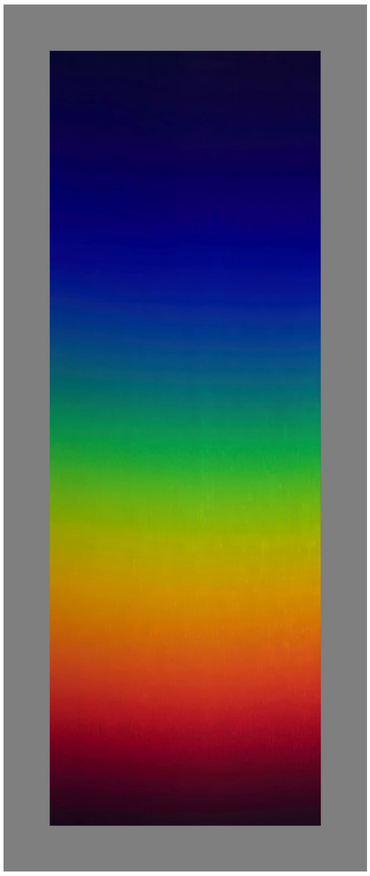

Fig. B: *Newton's spectrum*. Nowadays, the result of Newton's most famous experiment (Fig. A) can be replicated with a slide projector, whose light is sufficiently similar to sunlight. Against a dark background, an image of rich colours appears that contains (from top to bottom) blue, turquoise, green, yellow and red areas with blurred boundaries. (Photographed by Ingo Nussbaumer, cropped by Matthias Herder; source: O.M. [ML], colour plate 1.)

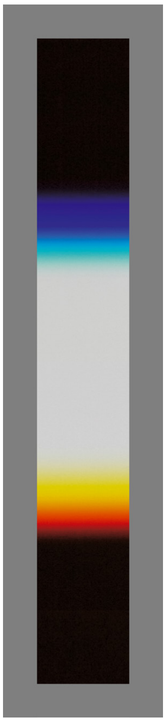

Fig. C: *Complementary ends of Newton's spectrum*. The upper end of Newton's spectrum (Fig. B) consists of cool colours (blue/turquoise), the lower end of warm colours (yellow/red). These colours become particularly saturated when the screen is moved closer to the prism than it is here (cf. Fig. H, upper part, positions 4 and 5). As the next figure shows, the cool colours are the compliments to the warm colours. (Photographed by Ingo Nussbaumer, arranged by Matthias Herder; source: O.M. [ML], colour plate 2.)

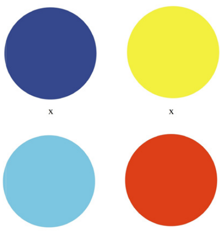

Fig. D: *Complementary colour pairs*. The left-hand side shows the two cool spectral colours (blue, turquoise), the right-hand side shows their complements (yellow, red). To elicit coloured afterimages, cover one of the two columns with white paper and stare at the black cross between the two visible patches for about 10 seconds. If you then look at the white paper without moving your eyes, afterimages will appear. (Image by O.M.)

The earliest documented meeting between Goethe and Ritter took place on September 20th, 1800.[19] Prior to the meeting, Ritter had performed galvanic experiments on his own eye. He had subjected his eye to electrical stimulation in order to observe its visual effect. He found that the stimulation leads to a sudden impression of *brightness* that slowly recedes; when the poles are reversed, however, there is a sudden impression of *darkness* that also slowly recedes.[20]

Thus Ritter was also investigating polarities: on the one hand, the polarity of positive and negative electrical poles; on the other, that of light and darkness. The results of Ritter's experiments suggest that these two polarities are connected.

As we know, Goethe was interested in the implications of the polarity of light and darkness for colours. We can thus assume that he asked Ritter to pay attention to colours in his galvanic experiments.[21]

Immediately after meeting Goethe, Ritter performed further experiments in which he observed colours caused by electrical stimulation: warm colours in the bright impressions and cool colours in the dark impressions.[22] The polarity Goethe had discovered between the ends of Newton's spectrum reappeared in an entirely new domain. When the experiments were finished the two met again. Afterwards, Goethe expressed his fascination to Schiller in a letter dated September 28th, 1800:

> I saw Ritter yesterday, an astonishing experience, a true heaven of knowledge on earth.[23]

Until now, scholars haven't been able to say what triggered Goethe's fascination. My reconstruction suggests that the young physicist told him about his most recent discovery, which was grist for Goethe's mill.[24] Ritter's many letters (e.g. to Ørsted or Frommann) reveal that he enthusiastically communicated his discoveries as soon as possible – he wore his scientific heart on his sleeve.[25] It is thus safe to assume that Ritter quickly informed Goethe about his galvanic colour observations.

Indeed, Ritter's observations on colour impressions following electrical stimulation quickly found their way into Goethe's notebooks, where he summed up the polarity of colours in their respective domains:

> The theory of colours submits is governed by polar laws:
> First in the opposition of the source +L –L [i.e. the polarity of light ("Lux") and darkness – O.M.]
> Then in the opposition +C –C [i.e. the polarity of complementary colours ("Colores") – O.M.]
> [...]
> Galvanism [...] also affects the theory of colours [...]
> *The physiological colours [are affected] by Ritter's discovery*.[26]

The initial success of their joint project encouraged Goethe and Ritter to look for polarities in other domains. A few months later, this plan lead to Ritter's famous discovery, as I'll show in the next section.

4 Ritter's Discovery of Ultraviolet Radiation

Around 1800, William Herschel had discovered infrared radiation beyond the red end of Newton's spectrum, but no radiation at the opposite end.[27] This bothered Friedrich Schelling, one of Goethe's allies in the fight against Newton. He expressed his concern in a letter to Goethe, dated April 17th, 1801:

> During my work on a new account of my philosophy of nature I happened to come across Herschel's experiments on the warming power of rays of sunlight. Am I wrong, or can these be fully understood by your theory of prismatic phenomena? Nonetheless, to be absolutely certain in this matter, and following the many explanations that I owe to your kindness already, I would like to ask for your explicit explanation of some aspects of your theory before I draw a connection between it and Herschel's experiments.[28]

In interpreting this passage, it is important to bear in mind how thin-skinned Goethe could be when his theory of colours was challenged. Schelling shows great restraint in his letter and does not explicitly say that Herschel's discovery presents a *prima facie* problem for Goethe's polar theory of spectral colours. Still, Schelling must have been acutely aware of the problem; he too was convinced of the polar nature of colour phenomena.

Schelling's request thus amounts to the following question: How can Goethe be right about the polarity of Newton's spectrum if the spectrum has an invisible extension on one side, but not on the other? Can the lack of symmetry suggested by Herschel's results be remedied?

Fig. E: *Goethe's colour wheel*. This colour wheel represents colour phenomena from different domains. Complementary colours are opposite each other. Thus, the cool end (blue/turquoise) of Newton's spectrum is the complement to the warm end (yellow/red). Furthermore, if the eye is electrically stimulated, an impression of either the cool colours or their warm complements appears, depending on the electrical polarity. (Image by Matthias Herder, following Nussbaumer [zF], book cover; source: O.M. [ML], colour plate 28.)

Schelling's worries were unwarranted. Ritter had already extended the symmetry beyond the red and the blue ends of the spectrum: on February 22nd, 1801, he discovered the effects of what is nowadays known as ultraviolet radiation.[30] This discovery secured him a prominent place in the annals of science. Ritter was aware of the significance of his findings and he knew how much they would delight Goethe. Thus, instead of informing his colleagues in Jena, he packed his bags and set off for Weimar, where he was received by Goethe the next day.[31] Although Goethe had just survived a life-threatening illness, they conducted several experiments together. Goethe must have been the second person to witness Ritter's ultraviolet experiment.

Goethe was electrified. He composed a long letter to Ritter, in which he suggested further experiments.[32] The letter was accompanied by two carefully drawn diagrams (Fig. H). In the following months, Ritter devoted much time to optical experimentation; his reports make clear that his optical experiments with spectral light owe much to Goethe.[33]

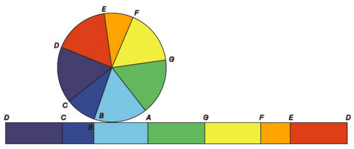

Fig. F: *Newton's colour wheel*. Newton rolled up his elongated spectrum into a wheel. He did not always divide his spectrum (Fig. B) into the five colours I have presented so far. Sometimes he divided it into infinitely many colours, sometimes into seven and sometimes into less than five (Shapiro [ACNC]OM]:613, 619, 625; Wülfing [FGS]OM]:96-98). His colour wheel is based on the proportions of the musical scale, which unfortunately does not reflect the colour distribution of the spectrum. This may be one of the reasons he paid no attention to the symmetrical structure of the spectrum, which Goethe took to be significant (Fig. C, D, and E). Most importantly, Newton did not place complementary colours opposite each other: there is no purple counterpart to the large green area AG. Goethe was the first to point out this lack of purple in Newton's system. (Image by Matthias Herder; source: O.M. [GZ]OM]:7, Fig. II.5.)

5 Ritter's Less Known Optical Discovery

In late July, 1801, Ritter made another discovery that he considered spectacular. On August 3rd, 1801, he wrote to his publisher:

> The fine weather of recent days has given me quite some joy. I have discovered beautiful things in the light [...] An optical unification with Goethe. Now Newton is truly overturned. Goethe's claim is correct.[34]

Ritter mentions the good weather because a clear sky was necessary for spectral experiments. His luck with the weather continued in the following weeks. By the end of the month, he wrote:

> Countless optical experiments. They truly refute Newton. Goethe's [...] view is confirmed.[35]

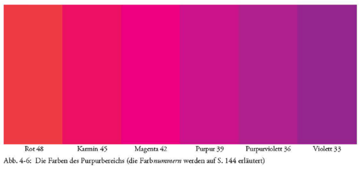

Fig. G: *Nuances within the purple area*. Newton's colour wheel reduces the visible area between the red and the blue end of the spectrum to a line between red and violet (Fig. F, line D). This eliminates a quarter of all saturated colours in our colour space, including purple (2nd area from the right) and the unitary hue of red (*far left*). Goethe considered the absence of these colours to be a significant deficiency of Newton's system (Goethe [EoNT]OM]:§506). If we construct a colour wheel with twenty equally-weighted colours, we would have to replace Newton's D-line with the six colours shown above. The finer-grained the colour wheel, the more colours would have to be inserted – e.g., no less than 16 colours for the sixty-part colour wheel created by the painter and colour researcher Ferdinand Wülfing. (Image reproduced with kind permission of its author; source: Wülfing [FGS]OM]:106, Fig. 4-6.)

These are surprising remarks by one of the leading scientists of Goethe's times. To this day, however, we do not know the details of the experiments Ritter mentions. Historians of science have ignored them and it is still an open question whether they can be reconstructed from Ritter's writings.[36]

Be that as it may, the close cooperation between Goethe and Ritter ended in 1804, when Ritter was appointed to the Bavarian Academy in Munich. He continued to publish the anti-Newtonian results of his optical experiments and was surprised that they did not cause more of a stir.[37] It appears that Goethe was not aware that Ritter had publicly argued in his favour and even published his letter suggesting further experiments.[38] In a footnote in his last optical publication, Ritter comments that he felt compelled to

> inform readers about a letter from privy counsellor von Göthe of Weimar, which I was honoured to receive before anyone in Germany had undertaken a thorough replication of Herschel's experiments, as they had [...] just become public. *From it [the letter], one will see that this man [i.e. Goethe – O.M.], who as an expert in optics is hardly understood*, already in 1801, and thus after the first reading of Herschel's essays, predicted outcomes for experiments [...] which were indeed brought about by their first public undertaking 6 years later. Furthermore, one will be grateful for my communication of the letter, *as it contains the author's [i.e. Goethe's – O.M.] thoughts on light and colour in a manner that allows for no more darkness*. The only reason I have delayed the publication, for which I would have always had permission, was that various things kept me from conducting the suggested experiments with the necessary precision.[39]

Ritter published not only Goethe's letter, but also the diagrams that accompanied it (Fig. H). While the colours have faded and thus do not precisely match the reconstructed colour wheel (Fig. E), they nonetheless make Goethe's intention clear. He requested measurements at several points in Newton's spectrum (presumably both thermodynamic and photochemical) and he requested the same measurements be made in the complementary spectrum. It would seem clear that he was expecting opposite results for the two complementary spectra.

What is more, Ritter claimed that Goethe's predictions were right. He published this in 1808, not long before Goethe published the *Farbenlehre* (1810). Ritter, however, was not to witness Goethe's publication; he died on January 23rd, 1810, lonely and desolate. With Ritter's death, Goethe lost his most important advocate in the field of physics.

6 Why Didn't Goethe Mention Ritter?

Surprisingly, Goethe never spoke publicly of his scientific collaboration with Ritter. Indeed, he tried to conceal it. In the *Farbenlehre*, he writes:

> Among the experts lending me assistance from their fields there are anatomists, chemists, scholars, philosophers, such as Loder, Sömmerring, Göttling, Wolf, Forster, Schelling; *but no physicists*.[40]

We will never know why Goethe didn't mention Ritter. It might have had to do with the fact that Ritter's scientific career ended in ruins.

Ritter had brought his name into disrepute with dowsing experiments. Premature reports of success did not withstand the scrutiny of an academic committee. Goethe may have wanted to avoid any link between this fiasco and the *Farbenlehre*. This interpretation is supported by the following remark in Goethe's diary, made on February 24th, 1810, shortly after Ritter's death:

> For lunch Mr. Frommann and Dr. Seebeck [Ritter's student – O.M.]. Ritter, whose journal is supplemented with fictions.[42]

We can only speculate what Goethe had in mind with this cryptic remark; possibly he suspected inaccuracies in Ritter's documentation of the dowsing experiments. Since the journal is lost, it cannot be verified that the documentation was indeed inaccurate.

Nevertheless, Goethe was not among those who posthumously dismissed Ritter's scientific achievements. When a journal published a sarcastic obituary for Ritter,[43] Goethe reacted with indignation:

> The essay on Ritter is despicable! All kinds of malice are printed everywhere [...]. Ritter had a difficult family background and all his announcements were unreliable; but he was very talented and had brilliant insights, and the way in which the journal lumps together correct and incorrect claims Ritter made is daft [...]. I am sending back the journal [...]
>
> As I said, Ritter was no good as a person and financially he pulled the devil by the tail (as the French

> say); both he himself and his achievements are hard to assess, but for that reason it is the unspoken duty of those who remain to bury what he lacked as a person and to uphold what his talent allowed him to achieve.[44]

Goethe uses Ritter's case to express the insight that scientists earn their place in history through their achievements, regardless of their errors. Thus, one should not judge Ritter by his poor choices.[45] His successes are remarkable enough: in addition to discovering ultraviolet radiation, he invented the rechargeable battery, pioneered electrochemistry and made countless further discoveries.[46]

As I have shown, Ritter's discovery of ultraviolet radiation arose from his collaboration with Goethe; a closer look into this collaboration revealed that Ritter not only endorsed the poet's views on colours and light, but also extended them with further experimentation.

Goethe's idea of polarity is fruitful for new research. This has often been denied, e.g. by Werner Heisenberg, the pioneer of quantum physics:

> Physicists may criticize Goethe's theory of colours because it cannot be developed into an exact science that leads to full control of optical phenomena. Colour phenomena that e.g., have not been observed can hardly be predicted by Goethe's theory.[47]

Heisenberg is mistaken. The diagrams Goethe sent Ritter (Fig. H) show that his idea of polarity predicts a temperature inversion when Herschel's method is applied to the inverted spectrum.[48] In response to my requests, physicists tested Goethe's prediction (Fig. K). It turned out that Goethe was right.[49] He would surely have been pleased.

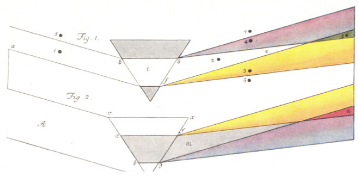

Fig. H: *Goethe's inversion of Newton's experiment*. The upper diagram depicts Newton's experiment (Fig. A), in which sunlight passing through the prism is split into spectral colours. The experiment takes place in a darkened chamber. Goethe shows how the spectral colours change according to the distance between prism and screen. Newton holds that if the screen is positioned very close to the prism (position 2), the coloured light rays have not yet separated enough from each other and are superimposed in the middle of the image. As a result, the green part of Newton's spectrum (Fig. B) is missing: the so-called cool edge spectrum is visible at the top of the image and the so-called warm edge spectrum at the bottom (Fig. C). At the right-hand edge of the diagram, the coloured light rays have separated far enough to create Newton's spectrum (blue/turquoise/green/yellow/red). Those are all the colours in Goethe's colour wheel (Fig. E), with the exception of purple. The lower diagram shows Goethe's inversion of Newton's experiment: from the left-hand side of the diagram, a shadow passing through the prism is split into the colours complementary to those of Newton's spectrum. At the right-hand edge of the diagram, the coloured rays have separated enough to create Goethe's spectrum (yellow/red/purple/blue/turquoise). Those are all the colours in Goethe's colour wheel (Fig. E), with the exception of green. In his letter to Ritter (discussed in Sec. 4), Goethe suggests a systematic series of measurements within and beyond the two spectra; black dots indicate the measurement points he had in mind. (This is the version of the diagram published by Ritter (Ritter (ed) [SGRv]OM]:729, 759, plate 3); there are a few negligible differences from Goethe's original version (see Matthaei (ed) [ZzF]OM]:99; No. 366); source: O.M. [GPoL]OM], Fig. 1).

Notes

1 I would like to thank Ferdinand Wülfing for helpful comments on a previous version of this text, Emanuel Viebahn for the English translation and Troy Vine for stylistic advice concerning the final version.

2 Goethe [EoNT].

3 Until recently, only the "Didactic Part" of the *Farbenlehre* (Goethe [EF]) was available in English (Goethe [GTC], Goethe [ToC]). Even with the translation of the "Polemic Part" (Goethe [ETN]), more than half still remains untranslated, namely the "Historic Part" (Goethe [MzGF]). A further difficulty for English readers is the lack of a translation of the instructive descriptions Goethe added to the 17 plates (Goethe [EzGF]).

4 Duck [I]OM]:xvi.

5 See the contribution from Grebe-Ellis et al. on page 142.

6 For a statistical analysis of all scientific reactions to Goethe's *Farbenlehre* that appeared during his lifetime see O.M. [GPSZ]OM], Sec. 5 – 10.

7 The *locus classicus* is Chang [CC]. Chang was not concerned with optics, but with chemistry.

8 There are three other scientists who are still well-known and who have commented on the *Farbenlehre*: Thomas Young [zF], Louis Malus [BFPü] and Thomas Seebeck [oUEo]OM]:331, 453-455. While the first two of these were negative, the latter was positive.

9 Goethe [BzO]/1, Goethe [BzO]/2.

10 Newton [O]OM]:21-24 (= Book I, Part I, Proposition II, Experiment 3).

11 Goethe [PF]OM]:190 (§4).

12 For a defence of my interpretation see O.M. [GPoL]OM], Sec. 5.

13 For this experiment see the contribution from Timm Lampert on page 132. The *locus classicus* is Newton [LoMI]ML]:3078/9; see also Newton [O]ML]:31-33 (= Book I, Part I, Proposition II, Experiment 6).

14 Goethe [EoNT]ML]:§132.

15 Contrary to what is often claimed, the purple centre of Goethe's spectrum does not necessarily decompose after the second prism (see the contribution from Grebe-Ellis et al., figure 5, page 147).

16 Duck [I]OM]:xxvii-xxviii, emphasis changed. I take it that the *experimentum crucis* provides a good, and possibly the best, illustration of Duck's point. Throughout his life, Newton was convinced that this ingenious experiment offered a conclusive proof of his theory (see e.g., the oft-quoted remark on page 172 in this volume from Turnbull (ed.) [CoIN]ML]/I:209). Less known is the following note he wrote fifty years later, referring to himself in the third person: "Newton founded his *Theory of light & colours* upon the experiment w^{ch} for its demonstrative evidence he calls Experimentum crucis" (quoted in Shapiro [GAoN]PE]:119). While Duck could have focussed on the *experimentum crucis*, instead he chose Goethe's criticism of Newton's white synthesis, which is a less sophisticated experiment (Newton [O]OM]:75/6, 87-91 (= Book I, Part II, Experiments 2, 10); Goethe [EoNT]OM]:§372; Duck [I]OM]:xxi-xxii).

Fig. I: *Goethe's inverted spectrum*. This inverted spectrum appears if the roles of light and dark in Newton's experiment (Fig. A) are interchanged, i.e. if the narrow ray of light is replaced by a shadow that is sent through the prism in light surroundings (Fig. H bottom). The resulting spectrum is just as big and colourful as Newton's. It consists of the colours turquoise/blue/purple/red/yellow. As Goethe was the first to produce the spectrum on a screen, it is known as *Goethe's spectrum*. (Photographed by Ingo Nussbaumer, cropped by Matthias Herder; source: O.M. [ML], colour plate 6.)

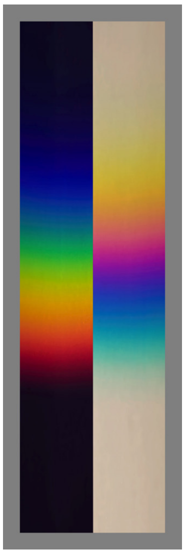

Fig. J: *Newton's spectrum compared to Goethe*'s. Each colour in one spectrum is adjacent to its complementary colour in the other. (Photos by Ingo Nussbaumer, cropped by Matthias Herder; source: O.M. [ML], colour plate 6.)

17 See, e.g., Duhem [ASoP]OM]:183-200 *et passim*, Popper [LoSD], Quine [TDoE]; for an interesting defense of Newton's proof, see the contribution from Lampert on pages 132–141. Goethe's criticism of Newton's claims to have *proven* his theory is not based on abstract philosophical considerations, but on the previously mentioned experimental facts concerning the interchangeability of light and darkness (Goethe [EzGF]OM]:86, translated in O.M. [PE]OM]:331). These considerations have gained further plausibility since we have been able to show that even Newton's *experimentum crucis* has a polar inversion (see footnote 15). Any proof this experiment is said to deliver is matched by a structurally analogous proof of the opposing theory, delivered by the inversion of the experiment (O.M. [PE]OM]:339n23). As this holds for *all* of Newton's experiments, his experimental proof cannot be strengthened by manifolding Newton's experiments – contrary to what Marcum claims (Marcum [NoLC]OM]:478 *et passim*).

18 This account is based on my German discussion in O.M. [GPSZ]OM], Sec. 2-4.

19 See Goethe's diary (Goethe [WA]OM]/III.2:306).

20 Ritter [VGBn]OM]/A:362/3.

21 Although we don't have written evidence for this assumption, it is documented that, in another case, Ritter conducted an experiment on Goethe's request (Klinckowstroem [GR]:144/5).

22 Ritter [VGBn]OM]/A:364.

23 See Goethe [WA]OM]/IV.15:123.

24 For details of the temporal succession of events, see Müller [ML]OM]:§III.2.7.

25 See the material in Harding (ed.) [CdHC]/II, Richter (ed.) [PRJW].

26 Goethe [VnA]:354/5; my italics; I locate this schematic overview between September 27th, 1800, and February 25th, 1801.

27 The *locus classicus* is Herschel [EoSo]/I, II.

28 Goethe [LA]/II.3:135.

29 Müller [GPmS].

30 Ritter [BzHN]/A. For an English discussion, see Frercks et al. [RD].

31 For the date of Ritter's discovery, see Ritter [BzHN]OM]/A:86. The ensuing meetings of Ritter and Goethe are documented in Klinckowstroem [GR]OM]:145/6 and Goethe [WA]OM]/III.3:7.

32 Goethe, Letter to Ritter dated March 7th, 1801 (see Goethe [WA]OM]/IV.15:189-193).

33 See, e.g., Ritter [BzHN]ML]/A:83, 99 (§1, §17); Ritter [VüS]OM]/B:357/8 (§IV). The similarities between the approaches of Ritter and Goethe become apparent if these two passages are compared to Goethe [AÜGW]ML]:7 and Goethe [EoNT]ML]:§6. For details, see Müller [ML]OM]:§III.2.8.

34 Richter (ed) [PRJW]OM]:112.

35 Richter (ed) [PRJW]OM]:116.

36 An important source is Ritter [VüS]/B. We hope to publish more research on this soon (Reinacher et al [PAPb]).

37 Ritter [VüS]OM]/B:353/4n.

38 Christoph Berger suggested to me that Ritter probably only voted in Goethe's favour to gain patronage in Jena. I find this suggestion unconvincing for three reasons: Firstly, it is contradicted by Ritter's writings after his move to Munich (see next quotation). Secondly, Ritter did not shy away from confrontation with Goethe even before he left Jena, such as on September 18th, 1801 (see Harding (ed.) [CdHC]OM]/II:216). Thirdly, Goethe did not always take advantage of his authority in Jena. For example, while he was in charge of the *Jenaische Allgemeine Literatur-Zeitung* (see Seibt [GN]:46/7, 51, 64-68), he did not prevent it from publishing negative reviews of his *Farbenlehre* (see Goethe [W]:204).

39 Ritter (ed) [SGRv]ML]:719-720n; my italics.

40 Goethe [MzGF]OM]:423; my italics.

41 For this unfortunate episode, see Ritter [NBzN]/I.1 as well as Nielsen [AKoL]OM]:132-134 and Strickland [CS].

42 See Goethe [WA]OM]/III.4:98.

43 Anonymous [WN].

44 Goethe [LA]/II.1A:736.

45 Forty years after his death, renowned scientists payed tribute to Ritter's accomplishments, among them du Bois-Reymond, a harsh opponent of Goethe's optical research (du Bois-Reymond [UüTE]OM]/1:313-372).

46 Schlüter [GRÜB]OM]:142-150. For an English summary of Ritter's research, see Nielsen [AKoL]OM]:114-118.

47 Heisenberg [GNFi]CB]OM]:57.

48 Goethe, Letter to Ritter dated March 7th, 1801 (see Ritter (ed.) [SGRv]OM]:724/5, 727).

49 Rang et al. [PADi]. For a discussion of this result, see O.M. [GPoL]OM], Sec. 3.

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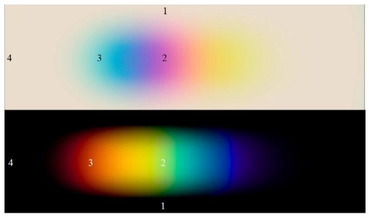

Fig. K: *The inversion of infrared heat radiation*. Lower part: Herschel began by measuring the temperature in the dark area beyond the long edges of Newton's spectrum (position 1). When he moved the thermometer to the green centre of Newton's spectrum (position 2), he detected an increase in temperature; the temperature increased further when he moved the thermometer into the red area of the spectrum (position 3). To his surprise, he found that the maximum temperature was beyond the red end of the spectrum (position 4), where we nowadays speak of infrared heat radiation. Upper part: When Matthias Rang and Johannes Grebe-Ellis repeated Herschel's experiment with modern means in Goethe's spectrum, they detected an inversion of relative temperatures. To begin with, a temperature measurement is taken in the *light area* beyond the long edge of Goethe's spectrum (position 1). If the thermometer is then moved to the purple centre of Goethe's spectrum (position 2), the temperature *decreases*; and it decreases further if the thermometer is moved into the blue area of the spectrum (position 3). Moving the thermometer further in this direction and beyond the end of the spectrum (position 4) leads to the minimum temperature, where we could speak of "infraturquoise coldness radiation". (Image by O.M.; source: O.M. [GGWE]:317, Fig. 10).

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