“Reconstructing” a colour theory

Unraveling the theoretical, material and methodological assumptions underlying James Sowerby’s *A New Elucidation of Colours* (1809)

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The image on the title page shows the coloured bands generated on James Sowerby's chromatometer through a "45° prism on stand" (inventory no. fk-0339) from the Teylers Museum. (Photograph by Dr. Hieke Huistra and Tim de Zeeuw.)

Introduction

De ontdekking
Als je goed om je heen kijkt
zie je dat alles gekleurd is
- K. Schippers,
De waarheid als de koe (1963)

When one looks at one's surroundings carefully, one will discover that everything, from the smallest object to the largest, has one or more colour(s). Therefore, it comes as no surprise that many natural philosophers through the ages used colours in the descriptions and depictions of animals, plants and minerals they studied. As the secretary of the Geological Society of London between 1811 and 1817 Arthur Aikin remarked: "In the works of Pliny and of the other ancient naturalists, colour is often the only external character that is mentioned."[1] Although in the modern sciences, colour "is rarely employed as empirical evidence in refined arguments,"[2] during the beginning of the nineteenth century colour was still seen as a decisive characteristic in the description of a specimen. In 1814 for instance the botanist, entomologist and painter of the *Wernerian Natural History Society* Patrick Syme (1774 - 1845) stated:

> In describing any object, to specify its colours is always useful; but where colour forms a character,[3] it becomes absolutely necessary. How defective, therefore, must description be when the terms used are ambiguous; and where there is no regular standard to refer to […] description, figure, and colour combined form the most perfect representation, and are next to seeing the object itself.[4]

According to Syme, colour is an essential aspect when one wants to depict objects.[5] Therefore, once an engraving of an object under scrutiny had been made, illustrators of atlases and other natural historical works could not circumvent using colours to render them realistically. However, many eighteenth and early nineteenth century natural philosophers and artists encountered the problem of unstable pigments: plant-based pigments could degrade and therefore discolour, and some mineral-based pigments could oxidise to a smudgy brown; making the renderings of specimens in atlases unreliable.[6] In 1774 the mineralogist Abraham Gottlob Werner (1749 - 1817) therefore proposed to refrain from using pigments in atlases for natural history, and instead suggested to create cabinets with specimens possessing a particular colour as a more reliable reference. However, assessing a mineral cabinet while a natural philosopher was out in the field naming the colours of specimens was quite impractical. Therefore, many naturalists at the end of the eighteenth and the beginning of the nineteenth century kept experimenting with pigments on different kinds of substrates, as for instance enamel or textiles, hoping these would prove to be

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1 Aikin as cited in Brian Dolan, "Pedagogy through print: James Sowerby, John Mawe and the problem of colour in early nineteenth-century natural history illustration." *The British journal for the history of science* 31.3 (1998): p. 298.

2 Peter Parshall "Preface: The Problem of Printing in Colour" *Printing Colour 1400-1700: History, Techniques, Functions and Receptions*, Brill, 2015, p.7.

3 With "character", Syme indicates that colour is the decisive property to differentiate between species.

4 Patrick Syme, *Werner's nomenclature of colours: with additions, arranged so as to render it highly useful to the arts and sciences, particularly zoology, botany, chemistry, mineralogy, and morbid anatomy: annexed to which are examples selected from well-known objects in the animal, vegetable, and mineral kingdoms.* Second edition, Edinburgh, William Blackwood, 1821 [1814], p. 6.

5 Syme, p. 6.

6 Annelies Van Loon, Petria Noble, and Aviva Burnstock. "Ageing and deterioration of traditional oil and tempera paints." In: *Conservation of Easel Paintings*, edited by Joyce Hill Stoner and Rebecca Anne Rushfield, Routledge, 2020, p. 218.

more durable solutions to the problem of stability.[7] A more remarkable alternative for the use of pigments on paper to visualise colours, was around the same time proposed by the botanist, mineralogist and engraver James Sowerby (1757 - 1822).

Some fifteen years after Sowerby had published the first entries of his *English Botany: or, Coloured Figures of British Plants, with their Essential Characters, Synonyms, and Places of Growth* in 1790, which had been hand coloured by his wife and children, he was in a state of despair when he discovered that most of the used colours had meanwhile faded or discoloured to a smudgy brown (see figure 0.1).[8] Therefore, he decided, just as Werner had done, that pigments were not reliable enough to communicate about colours. However, instead of relying on mineral cabinets as Werner had proposed, Sowerby had a different solution in mind. According to Sowerby, light is universally present. And, as Sir Isaac Newton (1643 - 1727) had demonstrated in his *Optics* (1704), making use of a glass prism the entire spectrum of colours could be generated.

Figure 0.1: Left: A specimen of Scabiosa arvensis from Sowerby's *English botany, or, Coloured figures of British plants, with their essential characters, synonyms, and places of growth: to which will be added, occasional remarks,* p. 28, published in 1790, in which the pigments have discoloured. Right: The same coloured engraving as published in the re-print made by his heirs in 1865, with more stable pigments. *English Botany, or Coloured Figures of British Plants*, ed. 3, by J.E. Sowerby et al vol. 4: t. 679.

[7] Giulia Simonini, "Organising Colours: Patrick Syme's Colour Chart and Nomenclature for Scientific Purposes." *XVII-XVIII. Revue de la Société d'études anglo-américaines des XVIIe et XVIIIe siècles* 75 (2018), par. 24-27.

[8] Dolan, p. 293.

Everywhere. Always. As long as there was light. After a few years of experimenting, in 1809, Sowerby published his *A New Elucidation of Colours, original, prismatic, and material.* In this book he set out a method with which all imaginable colours could be generated, and subsequently pinned down, in a standardised way. He explained his method by means of a description of a number of subsequent experiments with prisms, light, and various orderings of black patches painted on sheets of paper. With the devised approach, Sowerby claimed to have overcome the troubles related to colour creation, depiction and communication. He stated to have found “a sure foundation, laid by unerring Nature,” that would enable universal communication about colours that would never fade, so that “the mineralogist, the botanist and the zoologist may in future agree in their descriptions and ideas, so as to identify them to all parts of the world, and the remotest ages.”[9]

In secondary literature discussing Sowerby’s work on colour, it is consequently iterated that his methods were so complex that no scholar has adopted them, without an accompanying attempt to take up the glove and try to execute the experiments Sowerby proposes in his book.[10] Only historian of science Paul Henderson has attempted to rework one of the first experiments Sowerby describes in the *Elucidation*, and although he indicated that it was hard to obtain meaningful results, reworking Sowerby’s method does not seem impossible.[11] The field of Reconstruction, Replication and Re-enactment (RRR), in which reconstructions and reworkings of various objects and sources are executed, is currently thriving.[12] And Sowerby’s statement seems to explicitly challenge us to rework his experiments and see if we indeed are able to get standardised results based on his method. Furthermore, RRR has shown to be a helpful method to unravel theoretical assumptions that historical actors had in mind but that would only become explicit when their written discourse was being put into practice.

I shall argue that Sowerby is not only an interesting figure to investigate because he proposed a colour standardisation method that was very different compared to the mainly pigment and verbally focussed attempts of his contemporaries, but also because his versatile background - as an artist as well as a natural historian and natural philosopher - enabled him to write a theory about colours in which many ideas are proposed that deviate from other colour theories of the time, or synthesise multiple existing ideas in innovative ways.[13]

In my masterthesis, I will execute an in depth study of Sowerby’s colour experiments. I shall use a broad interdisciplinary array of methods, ranging from textual comparison of Sowerby’s ideas with other colour theories, reconstructions of Sowerby’s method with a variety of materials, to a participant-study investigating the feasibility and teachability of his method. In this way, I shall try to shed light on the theoretical, material and methodological assumptions underlying Sowerby’s method to universally standardise colours, and how this relates to the debates about colour theory, light, and colour standardisation during his lifetime.

Sowerby within the Historiography of Colour History

Within the field of the history of colour theory, regarding the eighteenth century, one of the main topics researched is Newton’s theory of light; to what extent it was adopted by his successors, and what arguments and alternative theories his opponents proposed. When it comes to the study of colour theories from the beginning of the nineteenth century, most attention is paid to the works of one of Newton’s greatest opponents: Johann Wolfgang von Goethe (1749 – 1832), who criticised almost everything Newton had written. This shifts attention away from studying colour theories generated in England, towards colour theories developed in Germany. As Friedrich

[9] James Sowerby, *A new elucidation of colours, original, prismatic, and material.* London, Richard Taylor and Co.,1809, p. 5.

[10] See for instance Elaine Ayers, ”Coded Colours: Botanical Histories of Colour Standardization," *The Site Magazine* 40.2 (2019): 35, or Dolan, p. 298.

[11] Paul Henderson, *James Sowerby: the enlightenment's natural historian*. Royal Botanic Gardens, Kew, 2015, p. 318; personal communication.

[12] Dupré et al. “Introduction.” In: *Reconstruction, Replication and Re-Enactment in the Humanities and Social Sciences*, edited by Sven Dupré, et al., Amsterdam University Press, 2020, p. 9-34.

[13] For an insightful overview of attempts for colour standardisation by Sowerby’s contemporaries that were based on pigments and verbal descriptions, see Giulia Simonini, "Organising Colours: Patrick Syme’s Colour Chart and Nomenclature for Scientific Purposes." *XVII-XVIII. Revue de la Société d’études anglo-américaines des XVIIe et XVIIIe siècles* 75 (2018).

Steinle has argued, this has led to the relative neglect of colour theories generated in England in the beginning of the nineteenth century.[14] When it comes to the colour experiments described by Sowerby, no study has ever devoted more than five pages to his ideas about colour. In my master thesis, I will try to fill part of this gap in the history of colour theory, by executing an in-depth analysis of Sowerby's *A New Elucidation of Colours.* It is interesting in this regard that some savants in Sowerby's time remarked that Sowerby's ideas closely resembled the theory of Newton, while others indicated that Sowerby's method would be perfectly in line with the ideas of Goethe.[15] In earlier research, however, it has never been investigated how Sowerby's theory is related to the conflicting theories of these two natural philosophers. In my thesis, I shall compare Sowerby's ideas with those of Newton and Goethe, in order to show that they correlate with neither of their theories. The comparative study will make clear that Sowerby's theory is built on different theoretical assumptions, for which he synthesises earlier ideas about colour in an unconventional way. Investigating Sowerby's colour theory will not only improve our understanding of his own work, but by adding alternative explanations to the field of colour theory during this period, it will sharpen our understanding of parts of dominant theories that remained largely unquestioned so far.

There are two more reasons why it is interesting to specifically focus on Sowerby as a case study to enrich the study of colour theories in this period. An important view in recent discussions of the eighteenth- and nineteenth-century colour theory is that although natural philosophers and physicists abundantly used Newton's colour theory for developing their own experiments and arguments, Newton's theory proved to be useless for artisans working with pigments.[16] Or, as historian and philosopher of science Friedrich Steinle elaborates:

> [O]ur image of the overall success of Newtonianism has to be seriously revised for the case of colours. Within natural philosophy, it appears, Newton's account of colours became firmly established in the course of the eighteenth century. […] On the side of colour practitioners, in contrast, things looked very different. Varied as the approaches were, most of them seemed to agree on the basic point that Newton's account, with its seven primary colours and mixing scheme, could not be used in practice. These approaches instead took the traditional three primary doctrine and developed if further. Put bluntly, the constellation appears as a clear opposition of two fundamentally different approaches - natural philosophy versus the systematisation of colour practice.[17]

Although Sowerby as engraver and illustrator and therefore "colour practitioner" did not use Newton's seven primary colours as a point of departure either, within the sketched framework it is interesting to see that Sowerby adopted other aspects of Newton's theory. Although Sowerby did not follow Newton's theory obediently, and disagreed with Newton's views on some points, he thoroughly analysed experiments from the second book of Newton's *Optics* (1704), in which Newton analysed the coloured rings generated by imperfections in the laminae of transparent minerals.[18] The colours generated in this manner formed the basis of Sowerby's own ideas about the generation of primary colours, that he developed further in his own work (see figure 0.2).[19] Furthermore, the fact that he built his method based on prismatic techniques was borrowed from Newton. And as Sowerby's biographer Paul Henderson has remarked, this was no scholarly exercise. Sowerby directed his work explicitly and primarily to artistic practitioners, with the intent to provide them with a "workable system" for their daily practice.[20] By analysing Sowerby's

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[14] Friedrich Steinle, "Colour Knowledge in the Eighteenth Century. Practice, Systematisation, and Natural Philosophy." In: *Colour Histories. Science, Art, and Technology in the 17th and 18th Centuries*, edited by Friedrich Steinle and Magdalena Bushart. Berlin, Boston, De Gruyter, 2015, p. 62.

[15] See for instance the correspondence between Goethe and Seebeck around 1816. WA IV 2 7, 228-230. - N 28-230. FDH Hs-16 966 b.

[16] Bushart and Steinle, p. V-VI.

[17] Steinle, "Colour Knowledge," p. 61.

[18] Isaac Newton, *The Second Book of Optics, part I: Observations concerning the Reflexions, Refractions, and Colours of thin transparent Bodies*, London, 1704, p. 198-200.

[19] Sowerby, p. 10-13.

[20] Henderson, p. 211.

method in detail, I will therefore nuance the current idea that Newton's colour theory was useless to colour practitioners; for Sowerby, it proved to be elemental.

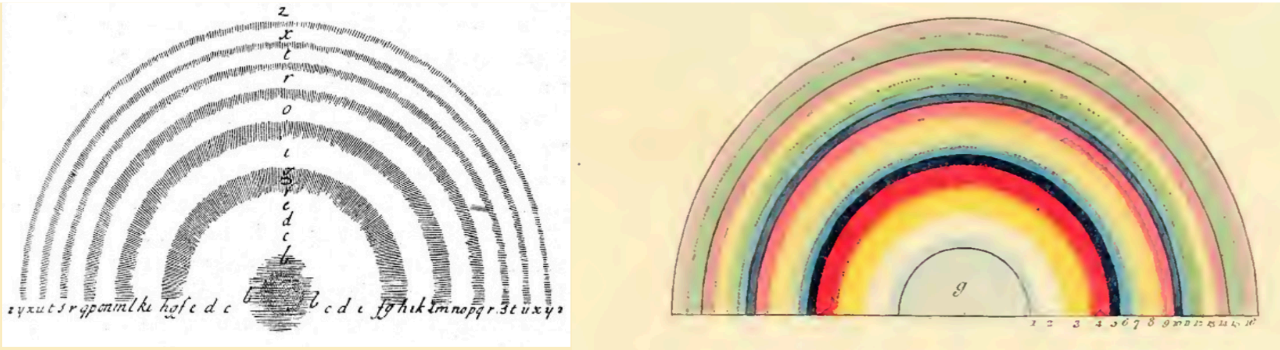

Figure 0.2: Left: Black-and-white engraving of the coloured bands as depicted in Newton's *Second book of Opticks* (figure 2, p. 200). Right: a coloured image of the same experiment as depicted on "Tab. 1" of Sowerby's *Elucidation*. Newton describes exactly the same colours in the text accompanying his engraving as Sowerby visualised in his depiction, which Sowerby also indicates himself (Sowerby, *A New Elucidation of Colours*, p. 10-12).

Furthermore, as becomes clear based on Steinle's quote above, within the history of colour theory during the late eighteenth and early nineteenth centuries, usually a sharp distinction is made between colour practitioners on the one hand, who used colours in their paintings and engravings, and natural philosophers on the other hand, who theoretically investigated the natural laws underlying the 'working' of colours. Using Sowerby as a case study, I will argue that this distinction could not always be made this easily. Although Sowerby was a man from a middle class family who was trained as a painter, and who sometimes faced preconceptions about his relatively low status as an artisan within a stratified Victorian society, he became a member of multiple learned societies in London; read the Philosophical Transactions; corresponded with an elaborate network of prominent natural philosophers discussing scholarly ideas, and he was very frequently the first person people consulted if they were in need of information about minerals, plants or fungi.[21]

Schatzberg argues that already during the fifteenth and sixteenth centuries a strong divide between artists and natural philosophers was in place that "would continue into the eighteenth century and beyond. These tensions played out in terms of an Enlightenment discourse about the relationship between art and science."[22] However, it is more widely accepted that before the middle of the eighteenth century many savants investigated phenomena from very different knowledge domains, including the sciences as well as the arts, such as the polymaths Athanasius Kircher (1602-1680), Simon Stevin (1548–1620), and the artist cum natural historian Simon Schijnvoet (1652-1727).[23] But somewhere during the nineteenth century, it is assumed that discipline formation took place. Savants who knew and investigated everything were replaced by specialists who focused on very narrow knowledge domains. However, most sources remain ambiguous about the time at which the polymath disappeared, and the confined specialist took

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[21] In chapter one, I shall substantiate this point more elaborately. An elaborate biography of Sowerby's activities in these domains is Paul Henderson, *James Sowerby: the enlightenment's natural historian*. Royal Botanic Gardens, Kew, 2015.

[22] Eric Schatzberg, *Technology: Critical History of a Concept*, University of Chicago Press, 2018, p. 54.

[23] About Kircher, see Paula Findlen, *Athanasius Kircher: the last man who knew everything*. Routledge, 2004; about Stevin, see C. A, Davids, et al. *Rethinking Stevin, Stevin Rethinking : Constructions of a Dutch Polymath*. Brill, 2021, and about Schijnvoet see Gijsbert M. van de Roemer, "The Serious Naturalist and the Frivolous Collector: Convergent and Divergent Approaches to Nature in D'Amboinsche Rariteitkamer." *Early Modern Low Countries* 3.2 (2019): 208-233; Tanne Bloks, "Simon Schijnvoet, een veelzijdig verzamelaar." *Schrijverskabinet*. 29 November 2022. Accessible via: https://www.schrijverskabinet.nl/artikel/simon-schijnvoet/

the stage. Sowerby (1757-1822) lived in this grey transition phase, during which according to the literature the know-all had disappeared; but no source claims firmly that the specialist had emerged.[24] Investigating Sowerby's colour theory against the larger background of his life and education, I hope to shed some light on the type of savants that were actively forming new knowledge during the beginning of the nineteenth century, and thereby contribute to our understanding of this transition phase.

Previous Sowerby scholarship and the structure of his *Elucidation*

In earlier scholarship, Sowerby's theory and method that would foster universally standardised communication about colours has not received more attention than a few pages. His work is mainly summarised in a single alinea in large historical overviews of colour theories in the eighteenth and nineteenth centuries. What many of these descriptions have in common, is that they point to the complexity, and therefore impracticality of Sowerby's chromatometer method.[25] I agree with these scholars that when Sowerby's description of the chromatometer is studied in isolation, it can be challenging to understand what he means. But notably, Sowerby himself did not present this description in isolation, rather, it is the conclusion of the thoroughly built up explanation and argument that forms his book *A New Elucidation of Colours*.

The *Elucidation* opens with observations regarding the colours that can be perceived in a wide array of natural phenomena, from waterfalls to telescopes to the slime of snails. His descriptions of these phenomena are not mere peculiarities, but, as I shall argue, are valuable if one wants to understand Sowerby's theory in depth. Thereafter, many preparatory experiments follow, in which Sowerby step-by-step introduces his readers to the aspects of colour generation that are of importance for understanding his chromatometer method.

In my thesis, I attempt to show that in order to understand Sowerby's theoretical, material and methodological assumptions, it is important to study Sowerby's *Elucidation* as a whole. Therefore, in the same spirit as Sowerby, I shall also explain the ideas underlying his chromatometer method step-by-step. However, I expect that it is informative for the reader to know beforehand what the explanations in my chapters will work towards; to have a general idea of what Sowerby's chromatometer looks like, what colours and tints it can generate, and how Sowerby intended one would communicate about colours with others using a chromatometer.

What is a chromatometer and how did Sowerby intend to communicate about colours?

A chromatometer is a surface of white paper, on which black shapes of specific sizes are placed in a specific array (see figure 0.3a). The upper five black forms are wedge-shaped, and if all five of them would be placed one after another in the horizontal direction, one would obtain a long line of gradually diminishing thickness from left to right. Because the paper sheet is of its practically limited dimensions, the black wedge-shaped line parts are placed underneath each other, with a similar white distance between each black part. Below this wedge-shaped line, a condensed form of a more abruptly diminishing breath is present, which has the shape of a "staircase", and which

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[24] Historian of science Ursula Klein for instance points to the difficulty of positioning German and French eighteenth-century artisanal-scientific experts during this transition phase, but on the other hand argues that there was a strong divide between artisans and natural philosophers. Ursula Klein, "Artisanal-scientific Experts in Eighteenth-century France and Germany", Annals of Science, 69:3 (2012), p. 305. See further Steven Shapin, "The Image of the Man of Science." In: *The Cambridge History of Science,* edited by Roy Porter, Cambridge University Press, 2003, p. 159-183; Agusti Nieto-Galan, "Between Craft Routines and Academic Rules: Natural Dyestuffs and the "Art" of Dyeing in the Eighteenth Century." In: *Materials and expertise in early modern Europe: between market and laboratory*, edited by Ursula Klein and Emma C. Spary, University of Chicago Press, 2010, p. 337.

[25] See for instance Neil Parkinson, *The History of Colour: A Universe of Chromatic Phenomena*. United Kingdom, Frances Lincoln, 2023, p. 91; Rolf G. Kuehni. *Color Space and Its Divisions: Color Order from Antiquity to the Present*. Germany, Wiley, 2003, p. 59; Ayers, p. 35, or Dolan, p. 298.

Sowerby added for more complex colour effects. I shall also discuss that lowest part, after first shortly having described the basic working of the upper chromatometer.

If someone takes a prism at hand and looks through it at the upper five wedges of the chromatometer, one would be able to perceive coloured bands at the borders between the black and the white. According to Sowerby, distinct bands in three colours would become visible: a blue band at the top of the black patches; a red band below the black patches, and a yellow band below every red band. (See figure 0.3b for my own reconstruction of these bands.) In chapter one I shall explain in more detail the importance of these three colours in Sowerby's theory, and why he claimed that distinct bands of colour are generated in this way.

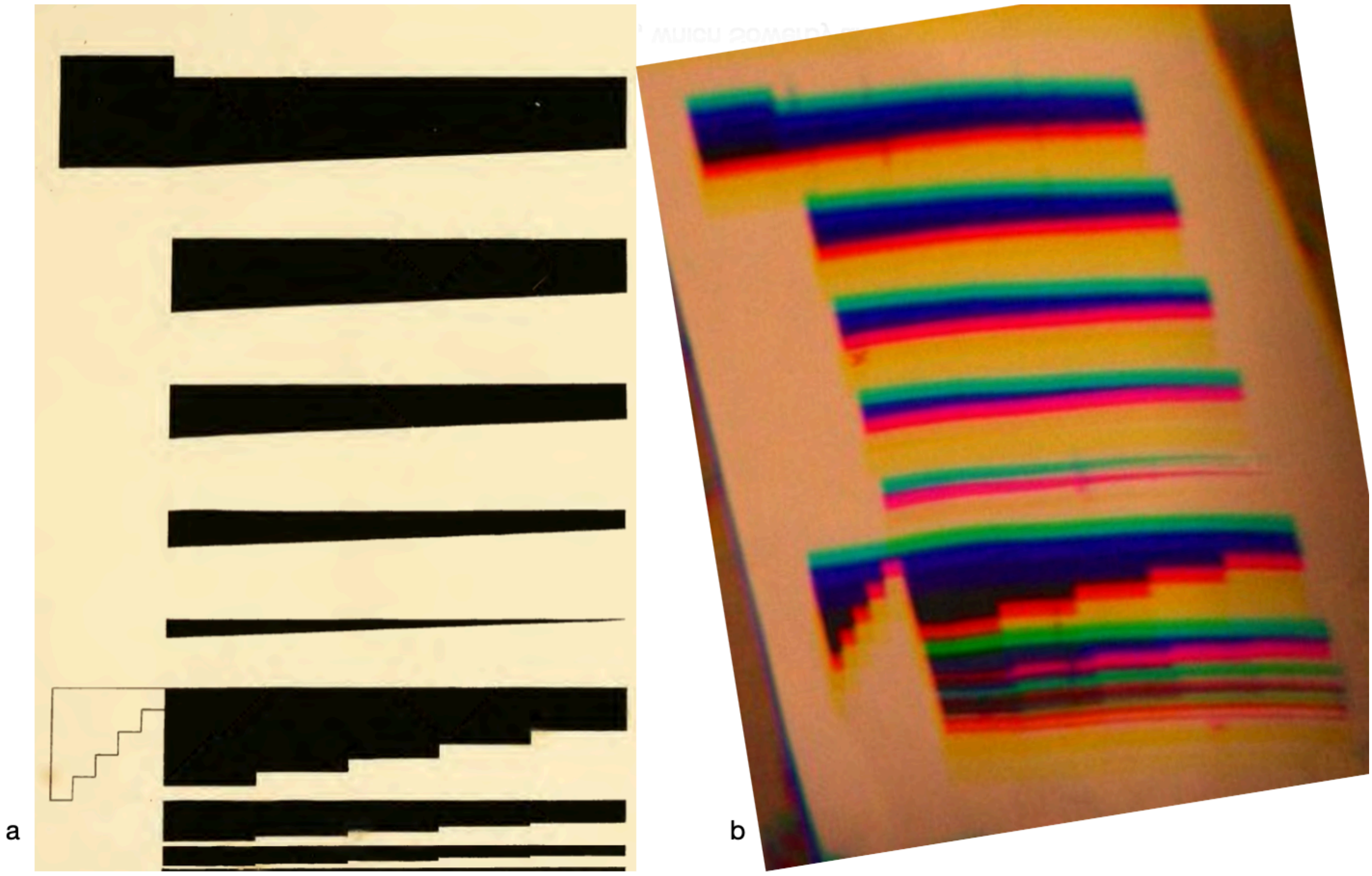

Figure 0.3: a) the chromatometer, as depicted on "Tab. 7" of Sowerby's *Elucidation.* b) An image of the coloured bands that become visible around the black patches of the chromatometer when one looks at it through a prism (photo by the author).

If one wanted to be able to generate all colours perceivable in nature, one would need to find a means to create other colours as well. According to Sowerby, this could be achieved by a different shape and arrangement of the black patches: at the staircase-shaped part at the bottom, that Sowerby named the "universal chromatometer", greens, oranges, purples and browns can be perceived as well.

Lastly, these colours appear in a large variety of tints in nature, like dark green and light green, so his device would need to be able to create different tints of colours as well. In order to achieve this, the diminishing breath of the black patches is of great importance to Sowerby. In his view, the diminishing breadth of the black would cause the colours generated along its borders to become paler and paler. The diminishing thickness of the black patches along the upper and lower part of the chromatometer would therefore enable one to see all tints of all the colours generated around them. Sowerby's theoretical ideas about the role of black and white in this regard, and their effect on the generated coloured bands, will be scrutinised in chapter two. Furthermore, chapter two will present an investigation of the materials that could be used to create this contrast and generate their accompanying colours.

Once one possessed a chromatometer and understood how to generate colours and tints on it, one could start communicating about colours with it. The working of the chromatometer as

Sowerby envisioned it is as follows: A person viewing an object with a certain colour that he or she wanted to pinpoint and communicate, would take a prism and a chromatometer at hand. Looking through the prism at the black-white interfaces, the clearly distinguishable lines of colour; coloured fringes created by the prism with their different tints along the chromatometer, would become visible. In this way, the primary observer could pinpoint the exact location of the desired colour and tint on the chromatometer, and measure the distance at which this tint was present (in inches). This numerical value, thereafter, could be communicated directly, in a written record, or could be noted alongside a drawing of a specimen in an atlas. Subsequently, the receiver of this value could take his/her own chromatometer, look through the prism, find the right distance, and would in this way directly see exactly the same colour as the first observer had seen.

Since Sowerby truly hoped that his method would become generally accepted and widely used, he gave various demonstrations of his method.[26] Still, as I have indicated above, his method appears not to have been adopted widely. In chapter three, therefore, I will present my investigation whether it is possible to educate his method to test-subjects within a limited amount of time. For this, I have performed a small experiment with a group of participants with a background related to the study of art and/or natural history.

Reconstructing a Colour Theory

In his biography of Sowerby, Henderson describes him as follows:

> Sowerby did not fit into any mould [...] unusual in his breath of scientific interests which he applied successfully, unusual in his desire to learn throughout his life and to impart his knowledge widely, unusual in going against the current practices by being at one and the same time his own researcher, writer, illustrator, teacher, publisher and bookseller; unusual in his considerable output of innovative, high quality and influential works; and unusual in becoming the patriarch of a successful line of natural historians.[27]

In order to understand the theory of a savant as versatile as Sowerby, I decided to approach his theory in a likewise broad, interdisciplinary way myself: combining comparative textual analysis, colorimetric analyses of materials, X-Ray Fluorescence spectroscopy, and a study with participants in order to shed light on Sowerby's theoretical, material and methodological assumptions. These methods will be explained in more detail in the specific chapters where I make use of them. But there is one method that I will use throughout my entire project; that will form a red thread throughout all of my chapters - although this will sometimes be mentioned more implicitly or explicitly: reconstruction.[28] My aim with the adoption of this method is threefold: firstly, it will enable me to investigate if, and how the method for colour standardisation and communication Sowerby proposed can be executed. Secondly, it will enable me to test if Sowerby's method indeed enables other scholars to communicate about colours in a universally applicable and standardised way. And thirdly and most importantly, reconstructing can be used as a method to gain insight in the ideas and assumptions Sowerby adopted while developing his method and writing his theory: reconstructing is not meant as a method to attempt to re-create the past "as it actually was," and to exactly re-live the steps and re-create the objects a past author has made. Rather, as historian of

[26] "3-2: Prospectus of *A New Elucidation and Arrangement of Colours*," and "3-3: Notice of Sowerby's Chromatometry lecture." 1 December 1808. Manuscript letters to members of the Sowerby Family: Box 5: Unattributed and Miscellaneous, DM1186 - Eyles Collection relating to the history of geology, Special Collections, University of Bristol Library.
[27] Henderson p. 8; 10.
[28] In line with Fors et al., I use the word "reconstruction" when I am referring to variations in materials used to make the chromatometer, or when I intent on retrieving assumptions or ideas that are part of Sowerby's theory but are implicit in his text. When it comes to aspects related to the performance of Sowerby's experiments and therefore the description of a process, however, I use the term "reworking". Fors, Hjalmar, Lawrence M. Principe, and H. Otto Sibum. "From the library to the laboratory and back again: Experiment as a tool for historians of science." *Ambix* 63.2 (2016): 93.

science Donna Bilak has explained: “It is fundamentally about learning how to know.”[29] The final goal of my thesis is not to re-create Sowerby’s *experiments* as accurately as possible, but rather to, by means of reconstruction, gain insight in Sowerby’s underlying colour *theory.*

Reconstructions, reworkings and replications (RRR) have been executed in many different contexts to help answering a great variety of research questions during the past decades. As historian of science Marieke Hendriksen concluded in 2020, these methods have meanwhile proven their value for research in the history of science, and therefore these “methods are here to stay“.[30] In *Reconstruction, Replication and Re-Enactment in the Humanities and Social Sciences*, an elaborate overview can be found of the wide array of disciplines in which RRR is used as a method.[31] For my master thesis, I shall limit myself to addressing a few key research projects of RRR in the field of optics. I shall explain how my master thesis builds upon insights generated in these earlier studies, and in what aspects my approach to RRR deviates from the types of questions earlier scholars tried to answer with RRR. As Sowerby used essential elements of Newton’s theory for his own method, and the latter has been extensively researched in contrast to the first, studying historical research on Newton’s theory proved to be useful. Firstly, I will explain why the approach of some reworking experiments in my view will not be helpful to clarify the theory and experiments of a savant. Then I will discuss how various reconstructions of researchers, on crucial aspects of Newton’s method, inspired my own research.

In 1970 historian of physics Roger H. Stuewer engaged in a debate about the reasons why Newton had not reported “interior interference fringes” based on his diffraction-experiments with a hair. Reworking the experiment Newton described led Stuewer to the conclusion that Newton would have been unable to perceive these fringes with his seventeenth century setup without digital means to increase the contrast of the fringes.[32] Historian of physics Yoshimi Takuwa tried to answer a similar type of question with the help of a reworking: could Newton have made the observations he claimed to have perceived in his *experimentum crucis* solely by means of the instrumentation he described in his earliest publications? Reworking the *experimentum crucis* with and without an additional lens in the setup, she concluded that Newton could only have seen the spectrum he reported to see with the addition of the extra lens he only added in later descriptions of the experiment.[33]

In my thesis, I shall deviate from the approach of Stuewer and Takuwa. I doubt if it is possible to get insight in the instrumental setup historical actors might have used by executing experiments until the outcomes exactly match their described observations and vice versa. Instead, I shall argue that if one and the same experimental setup could be used by actors adhering to multiple different theories, they would report different experimental outcomes based on the theory-ladenness of their observations. Therefore, in my view, no one-to-one relation between a reported observation and the used optical setup exists. By reworking similarly constructed experiments, and comparing my own observations with the colours various historical actors reported to have perceived, I shall try to gain insight into the plethora of observations and interpretations that can result from observing one and the same phenomenon. RRR in this way becomes an aid to unravel the described experiments in depth, and to make the theoretical assumptions underlying the descriptions and interpretations explicit.

The material aspects of prisms are the focus of research for historian of physics Dennis Nawrath. His reworkings of the prismatic experiments of Newton proved to be informative about the extent to which different types of prisms might influence created optical phenomena, and hence observations made by savants during experiments. Nawrath decided to let glassblowers remake - reconstructed - versions of historical prisms with different gradations of damage (air

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[29] Donna Bilak, "Out of the Ivy and into the Arctic: Imitation Coral Reconstruction in Cross-Cultural Contexts." *Berichte zur Wissenschaftsgeschichte* 43.3 (2020): 361.

[30] Marieke Hendriksen, "Rethinking performative methods in the history of science." *Berichte zur wissenschaftsgeschichte* 43.3 (2020), p. 321.

[31] Dupré et al. “Introduction.” In: *Reconstruction, Replication and Re-Enactment in the Humanities and Social Sciences*, edited by Sven Dupré, et al., Amsterdam University Press, 2020, p. 9-34.

[32] Roger H. Stuewer, "A critical analysis of Newton's work on diffraction." *Isis* 61.2 (1970): 188-205.

[33] Yoshimi Takuwa. *A study on the role of experiments in Isaac Newton’s optical research.* PhD dissertation, 2019. See also Yoshimi Takuwa, "The historical transformation of Newton’s experimentum crucis: Pursuit of the demonstration of color immutability." *Historia Scientiarum* 23 (2013), p. 137.

bubbles or veins). With these prisms, he showed that prisms of lesser quality would have strongly altered the created spectra (see figure 0.4).[34] This research not only made me attentive to the effect that the quality of historical prisms might have on the execution of Sowerby's method, but also provided me with ground to suspect that material factors might compromise Sowerby's method.

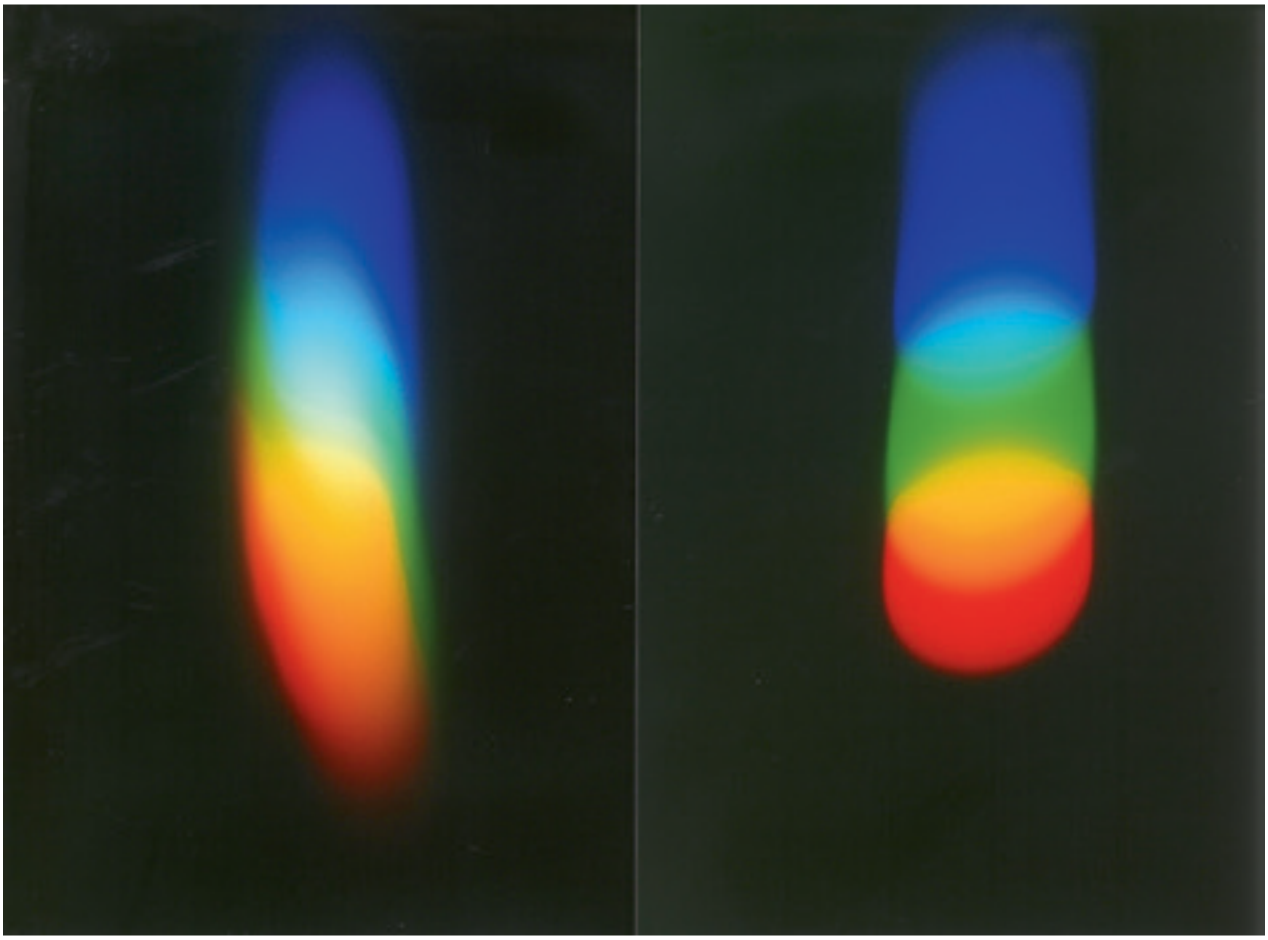

Figure 0.4: Left: the distorted spectrum generated by a prism containing large air bubbles, veins and other types of damage. Right: a spectrum created by a modern prism that showed no signs of damage. (Reproduced with permission of Dennis Nawrath.)

[34] See Dennis Nawrath, "Auf den Spuren Newtons - Experimente zur Farbzerlegung und Farbmischung mit Prismen." *Naturwissenschaften im Unterricht Physik* 110 (2009), p. 16-20.; "Die Analyse von Newtons Prismenexperimenten zur Untersuchung von Licht und Farben (1672) mit der Methode der Replikation–Ein Erfahrungsbericht." In: O. Breidbach, P. Heering, M. Müller, & H. Weber (Eds.), *Experimentelle Wissenschaftsgeschichte,* München: Wilhelm Fink Verlag, 2010, p. 73-105, and "Die prismatische Farbzerlegung durch Isaac Newton." *Kanonische Experimente der Physik: Fachliche Grundlagen und historischer Kontext*. In: Berlin, Heidelberg: Springer Berlin Heidelberg, 2022. p. 35-47.

Inspired by the theory of Goethe, the artist Ingo Nussbaumer, historian of physics Johannes Grebe-Ellis and quantum-physicist Mattias Rang investigated border colours generated not only at black-white interfaces, but also at interfaces between a broad range of different colours. Their research shows that the rainbow spectrum that Newton created in a darkened room is only one of many possible spectra that a prism can generate: each colour combination to which a prism is directed will create a "rainbow" made of totally different colours.[35] This made me suspect that Sowerby's chromatometer method might be compromised when a reconstructor of his chromatometer would be unable to find a perfectly white paper or a material with which deep black patches could be created.

The two research projects mentioned above led me to the adoption of a sub-class of reconstructions that are called "extensions". Historian and philosopher of science Hasok Chang has argued that many historical experiments are good candidates for "extensions"; variations in aspects of a historical method, mainly in its used materials, which are not mentioned in the original experimental descriptions, but that a curious reconstructor expects to be of influence on the final result.[36] Chang for instance describes an experiment on electricity by William Hyde Wollaston from 1801. When zinc is dissolved in an acid, hydrogen bubbles will appear. There is no consensus in modern literature about the cause of this phenomenon, nor was there consensus about it in Wollaston's time. To get better grip on the effect and more insight in what might be happening, Chang decided to vary the amount of zinc used for the experiment - something Wollaston did not describe. The effect of this variation lead Chang to develop not earlier formulated hypotheses about what chemical reaction might be going on, that in turn helped him to understand to a larger extent Wollaston's historical account, and its place within the historical discussion about the phenomenon.[37] In chapter two, I shall try to show that extensions of Sowerby's method in a similar way provided me with new insights regarding the creation of border colours, and that this modern detour proved valuable to understand Sowerby's historical theory to a larger extent. Furthermore, Chang argues that extensions are a good method to test historical claims and theories.[38] Therefore, extensions of Sowerby's initial experiment seem to be perfectly suited for the second objective of reconstructing in my master thesis: to test if Sowerby's method could indeed foster universal communication about colours.

Structure of the thesis

Many studies about the history of colour theory display an impressive scope with regard to the period and/or amount of savants under investigation. Or when case studies of individual colourists are presented, they are often combined in volumes that nonetheless try to grasp bigger pictures and larger developments based on a comparison of and synthesis between these case studies.[39] These macro-histories have presented us with many valuable insights, but a drawback of a large scale approach is that the methodology employed is often limited to historical and conceptual analysis only. This thesis strongly deviates from these trodden paths, by the adoption of a large array of methods to shed light on the ideas of one remarkable figure. I shall not present a traditional historical argument, that traces the development of a concept through time. Instead, my chapters will - I hope - show the value of an interdisciplinary approach, for which I invite philosophical concepts, reconstructions, colorimetric analyses and participant studies to become part of the research field of colour history. This explorative approach will help us to elucidate the interdisciplinary approach Sowerby adopted for his attempt of standardisation of colour communication, which he developed long before the word "interdisciplinarity" was coined. But

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35 See Ingo Nussbaumer, *Zur Farbenlehre: Entdeckung der unordentlichen Spektren*. Vienna: Edition Splitter, 2008, p. 176-178; Matthias Rang, "Coincidentia oppositorum - a thought on the relationship between Goethe's theory of colors and Newtons optics and todays physics." In: *Experiment Colour - Goethe, Newton and Optics.* Edited by C. Gerodetti and Z. Nordien. Kosmos Förlag, 2011, p. 17; Matthias Rang, Oliver Passon, and Johannes Grebe-Ellis. "Optische Komplementarität. Experimente zur Symmetrie spektraler Phänomene." *Phys J* 16 (2017): 43-49.

36 Hasok Chang, "How historical experiments can improve scientific knowledge and science education: The cases of boiling water and electrochemistry." *Science & Education* 20 (2011), p. 320-321.

37 Chang, p. 327-332.

38 Chang, p. 334.

39 See for instance Tanja Kleinwächter, C., Sarah Lowengard, and Friedrich Steinle, eds. *Ordering Colours in 18th and Early 19th Century Europe*. Vol. 244. Springer Nature, 2023.

although my thesis focusses on Sowerby as main actor, it might also provide new insights on theories of savants that have already been studied to a larger extent.

In chapter one, it will be investigated which theoretical explanations Sowerby provides in his *Elucidation* regarding the colours observable in nature and during experiments. I shall argue that the colours he describes to be able to observe when studying various colour phenomena are strongly influenced by his assumptions about the generation of colours; his observations are theory-laden. In order to make Sowerby's theoretical assumptions explicit, I shall compare his observations with observations that other colour theoreticians made during similar experiments, for which I shall focus on colour experiments of Newton and Goethe. This comparison enables me to show how fundamentally different Sowerby's theory is from the other two theories, and that these theoretical differences caused them to report the generation of different colours when studying the same phenomena. Furthermore, I shall show that the ideas that these men had about colours are strongly connected to their conceptions about the extent to which natural philosophers and artists could work with the same kinds of colours (material or prismatic). I shall argue that Sowerby's dual nature as an artist and natural philosopher enabled him to come up with a theory in which material colours could be equated to prismatic colours. It then becomes comprehensible, that the lengthy expose Sowerby provides in his *Elucidation* (before he explains the working of the chromatometer) is put in place for a purpose: it should convince people working with pigments that they could safely transfer to his chromatometer method based on prismatic colours.

In chapter two, I shall investigate the materials that are necessary for the creation of a chromatometer and colours upon it: paper, pigment and a prism. First, I shall explain Sowerby's ideas about the way in which a chromatometer can generate colours in more detail. It will become clear that black and white, and the contrast between them, are essential for Sowerby to create colours in different tints. Therefore, the whiteness of paper and the blackness of the patches painted upon it are of vital importance. But what materials were available to contemporaries of Sowerby, to create this contrast on a chromatometer? Would deviations in the used materials cause the generation of different colours on the device, thus compromising Sowerby's aim at universal communication about colours? And to what extent would the usage of various types of glass prisms influence what people might perceive? Investigating these materials shall enable me to see which of their properties influence Sowerby's chromatometer method. Furthermore, comparing these material aspects with the extent to which Sowerby paid attention to them, and embedding these findings within larger debates about the properties of these materials in the eighteenth and nineteenth centuries, shall enable me to make Sowerby's material assumptions explicit. Chapter two will form a continuation of chapter one, since it will make more theoretical assumptions explicit, and will also shed light on Sowerby's material assumptions. Furthermore, it will be investigated to what extent the used materials influence the possibility of communicating about colours in a standardised way, and therefore the reliability of Sowerby's method.

In chapter three another factor that might influence the succes of his method will be investigated: to what extent human perception of colours and their abilities to execute Sowerby's method influence the results they report. In order to examine this, I asked participants to use the chromatometer to code perceived colours into distances, and to decode "received" distances back into perceived colours. Since Sowerby's method was regarded to be difficult according to scholars who tried to comprehend it earlier, I decided to introduce the participants to Sowerby's theoretical and methodological assumptions step-by-step, and therefore led them through some of Sowerby's preliminary experiments during a teaching trajectory. Based on the reactions of the participants and their performance, I shall set forth to what extent I regard Sowerby's method to be learnable during a limited amount of time. Besides studying the teachability of Sowerby's method, I can in this way put Sowerby's claim of universal communicability to the test: do all participants indeed provide the same measured values when naming the same hues of colours? Or do differences in skill for using Sowerby's method, and/or physiological differences between individuals cause varying results?

In the conclusion, I shall synthesise how the studies in the three chapters informed us about the theoretical, material and methodological assumptions underlying Sowerby's *Elucidation*. "But does Sowerby's *Elucidation* present a colour theory?" I was asked. That depends on one's definition of what a theory is. If one defines a theory in the restricted sense in which Newton or Sowerby's contemporary colour theorist Thomas Young (1773 - 1829) presented it - as a list of clearly formulated propositions that are substantiated thereafter - than the answer would be "no". However, in my opinion there are more styles in which a theory can be presented. The field that studies the History of Science has during the last decades opened up to study a larger array of sources, historical actors and types of knowledge. Not only the gentleman scientist is regarded as interesting, but also his assistants during experiments; engineers and artisans who developed new techniques, and artists who showed their knowledge of the natural world in their depictions. We are shifting from a History of Science towards a History of Knowledge.[40] And within this new framework Sowerby's *Elucidation* is an excellent example of an alternative presentation of theoretical knowledge about colour. Although the *Elucidation* might seem elusive compared to a neat list of propositions, and though it therefore takes more effort to make Sowerby's ideas explicit, I shall show that Sowerby's text is founded on a plethora of theoretical, material and methodological assumptions, that together form a theory of colour, albeit a remarkable one.

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[40] See for instance Fokko-Jan Dijksterhuis, "Werelden van vernuft." Inaugural lecture, Vrije Universiteit Amsterdam, March 3 2017.

Chapter one: Elucidating coloured observations

James Sowerby, a nineteenth-century natural historian, natural philosopher and artisan, illustrated his books with hand-coloured drawings. He wanted these colours to be a reliable source for communication about nature. Unfortunately, the colours faded in time, for which he needed a solution. So, he searched for a standardisation of colours and developed a method that everybody should be able to use. His solution is described and explained in his book: *A New Elucidation of Colours*. Opening his book, however, we can see that Sowerby first describes many more observations of colour phenomena observable in nature, and thereafter describes a long list of experiments with prisms, before he finally introduces his chromatometer and its intended working. In this first chapter of my thesis, I will look at some of his observations of natural colour phenomena and some of Sowerby's prismatic experiments in detail.

These natural descriptions, as I shall try to show, are not penned down as mere peculiarities that might evoke the readers interest in the core of Sowerby's book. Instead, Sowerby very thoughtfully introduces certain analogies between colours and other natural phenomena, that not only can inform us about his theoretical ideas, but also about the extent to which Sowerby actively followed the scientific debates that were actual while he was writing his book. Furthermore, I shall argue that Sowerby uses these descriptions and experiments to convince his readers that light possesses the same properties as pigments, and that his readers could therefore reliably switch from pigments to a colour creating method that is based on light rays.

As I argued in the introduction, Sowerby makes an interesting case study because he was active in the domains of natural history and natural philosophy, and at the same time a renowned artist. In this chapter, I shall push this argument further, by showing how Sowerby combined strands of thought originating from all these different fields of knowledge into the theory that underlies his chromatometer method. In order to show this, I shall focus on the most important sub-part of his theory: his ideas regarding the existence and generation of colours. Central in this chapter is that the perception of colours is influenced by the information or theory an observer has in mind as a valid explanation for what he is seeing.

In *Patterns of Discovery*, philosopher of science Norwood Russell Hanson draws the disconcerting conclusion that different scientists may see different things in the same object,[41] and that this divergence in their perception is not something done deliberately after their initial viewing of the object; instead, their "theories and interpretations are 'there' in the seeing from the outset."[42] According to Hanson, observations are theory-laden: "There is a sense, then, in which seeing is a 'theory-laden' undertaking. Observation of *x* is shaped by prior knowledge of *x*."[43] Hanson continues by explaining how the influence of theory-ladenness on observations can be investigated:

> Examining how observers see different things in *x* marks something important about their seeing the same thing when looking at *x*. If seeing different things involves having different knowledge and theories about *x*, then perhaps the sense in which they see the same thing involves their sharing knowledge and theories about *x*.[44]

So, according to Hanson, when two people report to see exactly the same thing in *x*, this indicates that they have the same knowledge about what *x* is. But the opposite would also be true: if two people report to see different things when viewing *x*, this might be caused by a difference in their theoretical knowledge of an *x*. To substantiate his argument, Hanson directs his attention to colourless images and descriptions of objects. In this chapter, I shall investigate if different observers, based on the theories they have in mind, also see different colours when executing the same experiment.

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[41] Norwood Russell Hanson. *Patterns of Discovery: An Inquiry into the Conceptual Foundations of Science*. Cambridge University Press, 1975, p. 19.
[42] Hanson, p. 10.
[43] Hanson, p. 19.
[44] Hanson, p. 18.

In this chapter, I shall zoom in on a selection of the experiments Sowerby reports before introducing his chromatometer, and I shall describe what colours he describes to have observed during their execution. I shall show that the colours he mentions can be used to explicate many theoretical assumptions that constitute Sowerby's ideas, but remain implicit in his own text. In order to reveal these implicit ideas, I shall use Hanson's argument as my main method: in order to shed light on the theoretical assumptions underlying Sowerby's theory, I shall analyse some of his experiments by means of contrasting Sowerby's observations and explanations with observations and explanations given by other scholars who performed similar experiments. Through this comparison, it will become clear how their observations were influenced by the theories they had in their minds. For these comparisons, I selected two colour theorists who's ideas about colour have until now been regarded to be very similar to those of Sowerby: Isaak Newton and Johann Wolfgang von Goethe.

I shall argue that Sowerby's choice to work with prisms instead of pigments is to a large extent inspired by experiments described in Newton's *Opticks*, which Sowerby had studied in great detail. Therefore their methods of investigation show strong similarities. However, as soon as the colours both men reported to have seen during these experiments, and the theoretical explanations they gave for these observations are added to the picture, huge discrepancies will become visible.

Although no evidence has been found proving that Sowerby and Goethe knew about each other's ideas and theories in advance of the former publishing his *Elucidation* (in 1809) and the latter his *Farbenlehre* (in 1810), respectively, Goethe has shown particular interest in Sowerby's scholarly output in the years thereafter. It is thanks to Goethe's active involvement that Sowerby was elected as honorary member of the Jena Mineralogical Society in 1816.[45] Henderson suggests that this nomination was largely because Goethe hoped to gain access to Sowerby's extensive mineral collection and to receive editions of his illustrated publications. But besides these interests, Goethe also showed a keen interest in Sowerby's colour theory. We know from his correspondence that Goethe invested a lot of effort in order to obtain a copy of Sowerby's *A New Elucidation*.[46] Furthermore, according to his diary, Goethe studied and re-consulted the book in various years of his life, and discussed its contents with multiple other German savants.[47] However, when it comes to Goethe's appreciation of the *Elucidation*, he is very brief: he states that Sowerby executed experiments similar to his own, which generated the same findings. But Sowerby, he claimed, obtained these findings in a much messier way compared to his own, rightful way of investigation.[48] In this chapter, I shall set forth that both men indeed had very different theoretical assumptions underpinning their ideas about the way in which border colours

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[45] Henderson, p. 274-275.

[46] On 29 December 1814, Seebeck seems to be the first scholar to bring Sowerby's *A New Elucidation* to Goethe's attention, see Seebeck an Coethe. GSA 26/L,4a Bl. 24-27; Nr. 6-7. On 5 November 1816, Prof. Schweigger is able to provide Goethe with a copy of colour tab 4 of *A New* Elucidation (via Knebel), see Knebel an Goethe. GSA 28/512 St. 13. This evokes Goethe's interest, and therefore he asks Configliachi during a visit on 16 November for more specifications regarding its printer (Taylor) and year of publishing (1809), Configliachi an Goethe, GSA 28/74 Bl. 189. Thereafter, Goethe asks Seebeck to obtain the book for him. Who reports on 7 Januari that he has ordered the book, but has not yet received it, Seebeck an Goethe. GSA 26/L1,18,2 Bl. 102 103. On 27 Februari, Vogel informs Goethe that their contact person in London, Herr Hüttner, has been searching for the book; that two different printers in London are named Taylor, but that none of them knows about Sowerby's book, C. S K. Vogel an Goethe, GSA 26/L1,18,2 Bl. 112. Finally, on 7 April 1817, Vogel is able to send the book to Goethe. In the accompanying letter, he explains that Taylor was only the printer of Sowerby's book, but that Sowerby himself acted as the publisher, and therefore that it only could be bought directly from Sowerby's home address, C.G.K. Vogel an Goethe. GSA 28/74 Bl. 185.

[47] We know that Goethe noted in his diary to have studied the book between 8 April and 25 Juli 1817, see Goethe Tagebuch. WA III 6, 33; Goethe Tagebuch. WA III 6, 54; Goethe Tagebuch. WA II 6, 82. He borrowed a copy of *A New Elucidation* between 23 May and 30 November 1819 from the Weimarer Bibliothek to re-read it, in order to discuss its contents with Herr Dawe during these months, see 24. Mai. Goethe Tagebuch. WA IH 7,50, and with Seebeck during December of the same year, see 30. Dezember. Goethe an Seebeck. WA IV 32, 133 f.

[48] Letter from Goethe to Seebeck, 8 November 1816. WA IV 2 7, 228-230. - N 28-230. FDH Hs-16 966 b.

are generated. By contrasting Sowerby's theory with Goethe's *Farbenlehre*, it will become clear that these similar experiments did not lead to identical results. In contrast, I will argue that their differing theoretical assumptions strongly influenced the observations they reported.

Furthermore, I shall interweave some valuable insights generated by my own reconstructions of Sowerby's experiments. When I tried to rework Sowerby's experiments myself, I quite frequently stumbled upon unclear passages in his text, where clear instructions or a theoretical embedding of occurring phenomena seemed to be lacking. This evoked more questions than I was able to answer based on Sowerby's *Elucidation* or on my reworking of the prismatic experiments. When consulting the *Opticks* and Farbenlehre, I could find some possible - albeit in most cases different - answers to these questions. The combination of my own reconstructions with the found differences in explanations provided by these three men: Newton, Sowerby and Goethe, furthermore gave me insight in the explanatory power of their theories.

A short biography of Sowerby

In this chapter, I shall argue that the observations Sowerby describes regarding his experiments are strongly influenced by his versatile background as a natural historian, natural philosopher, and artist. A short biographical sketch of his life is useful to better comprehend how Sowerby's way of thinking has been shaped by these schools of knowledge, and how and why he actively portrayed himself as knowledgeable in all.

If everything in Sowerby's life had developed as planned, he most likely never had been submersed in the field of natural history to the extent he has been. His parents intended that Sowerby should become a marine painter, for which they arranged an apprenticeship by the prize-winning painter Richard Wright. Unfortunately, Wright died before the official completion of Sowerby's apprenticeship due to the complications of a stroke.[49] Deprived of his prospect of the title of master painter, Sowerby decided to start an apprenticeship with another painter, named William Hodges. However, Hodges treated him so badly that Sowerby himself decided to end this apprenticeship prematurely.[50]

Without any official qualification, Sowerby still needed to find a means to sustain himself. One way or another, he came in touch with the natural historian William Curtis, who was looking for talented draughtsmen to paint the coloured plates for his botanical work *Flora Londinensis.* Sowerby's sharp observing eye for detail and his skill in drawing were soon recognised, which also provided him with commissions by other natural historians in Curtis network.[51] His drawings turned out to be so promising, that Sowerby was furthermore admitted to join the Royal Academy Schools in 1777 for free, where he received education of some of the greatest professors in painting in London.[52]

After now successfully completing his education, Sowerby decided to continue illustrating botanical and other natural history books. He contributed to the illustration of some fifteen natural historical periodicals and books directed by others, who frequently added Sowerby's name as illustrator in their advertisements as a proof of quality of the illustrations, in order to increase their sales. At that time in his life, Sowerby made the unusual decision to take charge of his own natural historical projects: he became the publisher of his own works, for which eminent natural philosophers were allowed to submit learned textual descriptions to accompany his engravings.[53] When it came to the field of mineralogy, Sowerby experimented, corresponded and studied even to such an extent, that this painter established himself a reputation as one of the leading experts in the field. Therefore he not only made the engravings for this type of work, but he also let the accompanying descriptions flow from his own pen.[54]

Sowerby actively corresponded with natural philosophers, and he was elected as a member or honorary member of various learned societies, including the Linnean Society, the Geological Society, the London Philosophical Society, the Jena Mineralogical Society, the Physical Society of Göttingen, and the Lambeth Chemical Society.[55] Furthermore, he actively engaged into spreading knowledge of natural history to a wider audience, for which he built a

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49 Henderson, p. 19-20.
50 Henderson, p. 21.
51 Henderson, p. 22, 46-51.
52 Henderson, p. 29.
53 Henderson, p. 46-51; 101; 307-308.
54 Henderson, p. 191-193; 275-277.
55 Henderson, p. 273-275.

museum in his backyard in 1796. In here he displayed a steadily growing collection of plants, stuffed animals, self-made models of fungi, minerals, shells, meteors and other curious objects. People were allowed to visit this museum for free on each first and third Tuesday of the month between 11 am and 3 pm.[56] Furthermore, he presented optical experiments with prisms during public lectures in the museum, and for a small fee he would, by appointment, privately instruct people about crystallography or drawing.[57]

Sowerby's claim for the possession of natural historical knowledge was, however, not approved by everyone. When Sowerby accepted to contribute to the engraving of plants for the *Flora Graeca* by John Hawkins and Thomas Platt - of whom was known that they treated the illustrators in their company as inferior servants - this soon led to a heavy quarrel between the main authors and Sowerby.[58] The commissioners not only fiercely criticised the quality of Sowerby's work, but also they retroactively refused him the right to publish the work, since he was a mere artisan.[59] At another instance, Sowerby's expertise was sought regarding fungi by Mr John Knowles, the Secretary to the Committee of Surveyors of the Navy Office, to help mitigating the rotting process that had already damaged the East Indian Company ship the Queen Charlotte. Although the rotting was stopped after adopting Sowerby's recommendations for treatment, which prevented the ship from total rebuilding, the Naval Board refused to pay Sowerby for his advice, stating that Sowerby had overstepped his rank as a mere draughtsman by claiming that it was thanks to his knowledge that the ship had been saved.[60]

In sum, after his initial training as a painter, Sowerby has spent large part of his life expanding his knowledge as a natural historian, actively developing his expertise on many subjects. This was acknowledged by many, but contested by some, because of his original and continued status in British society as an artisan. I shall argue, that in his *A New Elucidation of Colours*, Sowerby actively uses *self-fashioning* strategies to prove his connectedness to and knowledge of the field of natural history. Analysing his assumptions regarding the origin of colours, it will become apparent that his natural historical knowledge went hand in hand with his background as a painter, and that his ideas about colours were strongly influenced by his training as a draughtsman.

Sowerby's watery construction of authority

In the introduction to his *Elucidation*, Sowerby narrates that he had a conversation with a "friend" who claimed that, in accord with the theory of the great Sir Isaac Newton, seven primary colours exist in nature:

> It was observed to me by a very good friend, "that as the seven tints were permanent, that was an evidence of their sufficiency as primitives and their original derivation, and that water was perfect in itself, although it was found to consist of hydrogen and oxygen."[61]

According to Sowerby, this friend proposed an analogy between these primary colours, and the chemical composition of water. Sowerby disagrees with both views, and replies with an elaborate argument that is worth quoting in full:

> The latter [water] was once thought a pure element, and led to wrong conclusions. The former [the seven colours] being thought perfect, it will be evident, has also caused wrong conclusions; and as water is not necessary to be formed to produce one of its original parts, hydrogen or oxygen, so, it will be less necessary to mix yellow and red and yellow and blue to make a yellow! When yellow is originally and necessarily so, to form the very ingredients so unhappily combined, and leading into continued and self-proving errors. Thus water does not form hydrogen and oxygen, but hydrogen and oxygen form water. Yellow, red, and

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56 Henderson, p. 126-129.

57 Henderson, p. 209-211; 214.

58 Krimbas, C. B., H.W. Lack, D.J. Mabberley, "The Flora Graeca Story." *The Historical Review/La Revue Historique*, 1, (2005), p. 281.

59 Henderson, p. 8; 152-157.

60 Henderson, p. 237-245.

61 Sowerby, p. 6.

> blue, I presume, therefore, will more properly form the remainder of the seven prismatic tints, than either two or more of the seven will form a single primary colour.[62]

By his introducing the supposed analogy between the composedness of colours and the composition of water out of hydrogen and oxygen, Sowerby can realise two of his objectives. Firstly, this enables Sowerby to show that he is knowledgeable about recent chemical developments. From antiquity onwards, natural philosophers had adopted Aristotle's view that water - as one of the four elements - was a principal building block for all other substances on earth.[63] In 1783, at a meeting of the French Académie des sciences, the chemist Antoine-Laurent Lavoisier had announced that water is no indivisible primary substance, but that it consists of two components: oxygen and hydrogen. Lavoisier and Pierre-Simon Laplace demonstrated experimental proof of this claim in front of several French colleagues and a distinguished visitor from the Royal Society of London, Charles Blagden, and the finding was also communicated by Laplace to the intelligencer Jean Deluc in London four days later.[64] In 1791 the scientific journalist William Nicholson and the surgeon Anthony Carlisle demonstrated the splitting of water in hydrogen and oxygen for the first time in London, but this new view about the constituents of water remained highly contested.[65] On 20 November 1806 the chemist Humphrey Davy re-performed the splitting during his first Bakerian Lecture, "On Some Chemical Agencies of Electricity" before the members of the Royal Society, claiming that this could indeed be proven with a voltaic pile.[66] In the following years, Lavoisier's idea became accepted to a growing extent in England, with only authors of such "minor importance" that Davy did not feel the need to take them seriously, questioning the idea.[67]

Although Sowerby does not mention the names of Lavoisier, Laplace or Davy explicitly in his *Elucidation*, we know from the auction catalogue of his library that was drawn up after his death, that he possessed two volumes of Lavoisiers work.[68] Furthermore, Sowerby was an active correspondent with the Davy-family, exchanging much information about chemical developments, and Humphry Davy visited Sowerby's museum.[69]

Sowerby's contemporaries would very likely have understood that by mentioning the composition of water, he referred to this recent change of thought, in which the old Aristotelian view of water as a primary substance was contested because of the discovery of oxygen as one of its constituents. This gave Sowerby a means to show his own knowledgeability of recent developments, and hence portrail of himself as someone who engaged with debates in natural philosophy.

The second objective of Sowerby with drawing up this water-colour analogy was to show that ideas about the principle building blocks of nature, that had been stated by a great authority and held for centuries, were not immune to revisions. In a similar way as Lavoisier had shown that Aristotle's ideas about the makeup of the world was wrong, because water turned out not to be a primary building block - but a compound formed by hydrogen and oxygen - Sowerby challenges

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[62] Sowerby, p. 6.

[63] Klein, Ursula. "A Revolution that never happened." *Studies in History and Philosophy of Science Part A* 49 (2015), p. 81.

[64] Donovan, Arthur. *Antoine Lavoisier : Science, Administration, and Revolution*. Cambridge University Press, 1996, p. 133-134; 154.

[65] Golinski, Jan. *The Experimental Self: Humphry Davy and the Making of a Man of Science.* University of Chicago Press, 2016, p. 102; 111.

[66] Golinski, *The Experimental Self,* p. 108.

[67] Golinski, *The Experimental Self,* p. 111.

[68] Thomas and Stevens (Firm), "Entry no, 747" in: *A catalogue of the remaining portion of the celebrated collection of ... James Sowerby, which includes many rare examples of the natural history of Great Britain ... which will be sold by auction by Messrs. Thomas & Stevens on the premises, No. 2, Mead Place, Lambeth ... June 23rd, 1831*. British Library, shelfmark 728.e.20. https://explore.bl.uk/BLVU1:LSCOP-ALL:BLL01010557611

[69] See for instance "Letter from Sr. Humphry Davy to Mr. James Sowerby," 1 July 1800. The Sowerby Collection 1739-1985. Natural History Museum, London; Golinski, Jan. "Humphry Davy: the experimental self." *Eighteenth-Century Studies* (2011), p. 16-17.

the long cherished idea of the great Sir Isaac Newton, uttered by his “friend”, that seven primary colours would exist in nature, including green, orange and the purples. These colours, as Sowerby intends to show in his book, are in fact also composed of other building blocks: the three “real” primary colours: red, yellow and blue:

> I would not have insisted so much on this subject, but that the present improving state of natural science seems to demand a concordance of the primitives of prismatic tints and substantial colours, which appear so much to depend on each other; and it has been understood by many, from the time of sir Isaac Newton, that the prismatic tints may be imitated by what I would consider as simple primitives, viz. yellow, red, and blue.[70]

Ursula Klein has argued that Lavoisier made the step to start calling the smallest building blocks in chemistry “simple primitives”. We can see in the quote above that Sowerby transfers Lavoisier’s phrasing to the domain of colours.[71] Furthermore, we can see Sowerby arguing for an attempt to find a means to connect ideas about the prismatic colours generated in prisms as has been done by Newton, with observations made based on the “substantial”, or material colours that painters use, for which was generally known that yellow, red, and blue were the only colours necessary to make all other colours on the painters palette.[72]

Natures proof of painters colours

As a first proof that nature’s colours are commensurable with the three primary pigments of painters, Sowerby sets forth to study coloured rings that can emerge in the laminae of transparent minerals. We know with certainty that Sowerby’s mineral collection has contained over 5000 specimens, since these were sold to the Natural History Museum after his death.[73] On top of that, he received many special minerals from mineralogists, collectors and enthusiasts in the hope that Sowerby would include engravings of them in his *British Mineralogy*-series. The building up of this collection gave him the opportunity to study a large array of minerals in detail. Sowerby was a renowned engraver, and he was particularly praised for the observational skill that made his drawings astonishingly accurate.[74] Sowerby not only described the appearance of minerals, he also reported their optical properties, as we can for instance read in his description of metastatic carbonate of lime:

> The double refraction is seen, when held in certain directions, by the prismatic tints, which are very beautiful, and in some positions catch the rays of light, so as to show them in great abundance in the numerous flaws.[75]

Already among the engravings Sowerby published between 1802 and 1804, we can find depictions of transparent stones that contain rings in various colours (see figures 1.1, 1.2 and 1.3). So we know that he had perceived these phenomena some years before the publication of the *Elucidation* in 1809. In the descriptions of the transparent stones in the *British Mineralogy*-series, however, he only mentions that around the flaws in these minerals “prismatic tints” are visible.[76] The explanation of the generation of these prismatic tints had to wait until the publication of his *Elucidation*, in which he shifted from describing these minerals and their optical properties to actually experimenting with them:

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[70] Sowerby, p. 6.
[71] Klein, p. 87.
[72] Alan E. Shapiro, "Artists' colors and Newton's colors." *Isis* 85.4 (1994): 600-630.
[73] Conklin, Lawrence H. "James Sowerby, his publications and collections." *The Mineralogical Record* 26.4 (1995), p. 91.
[74] Conklin, p. 88.
[75] Sowerby, *British Mineralogy*, vol. 1, Tab. XXXV, p. 164.
[76] Sowerby, *British Mineralogy*, vol. 1, Tab. II, p. 26; Tab. XXXV, p. 164 and Tab. LXVII, p. 292.

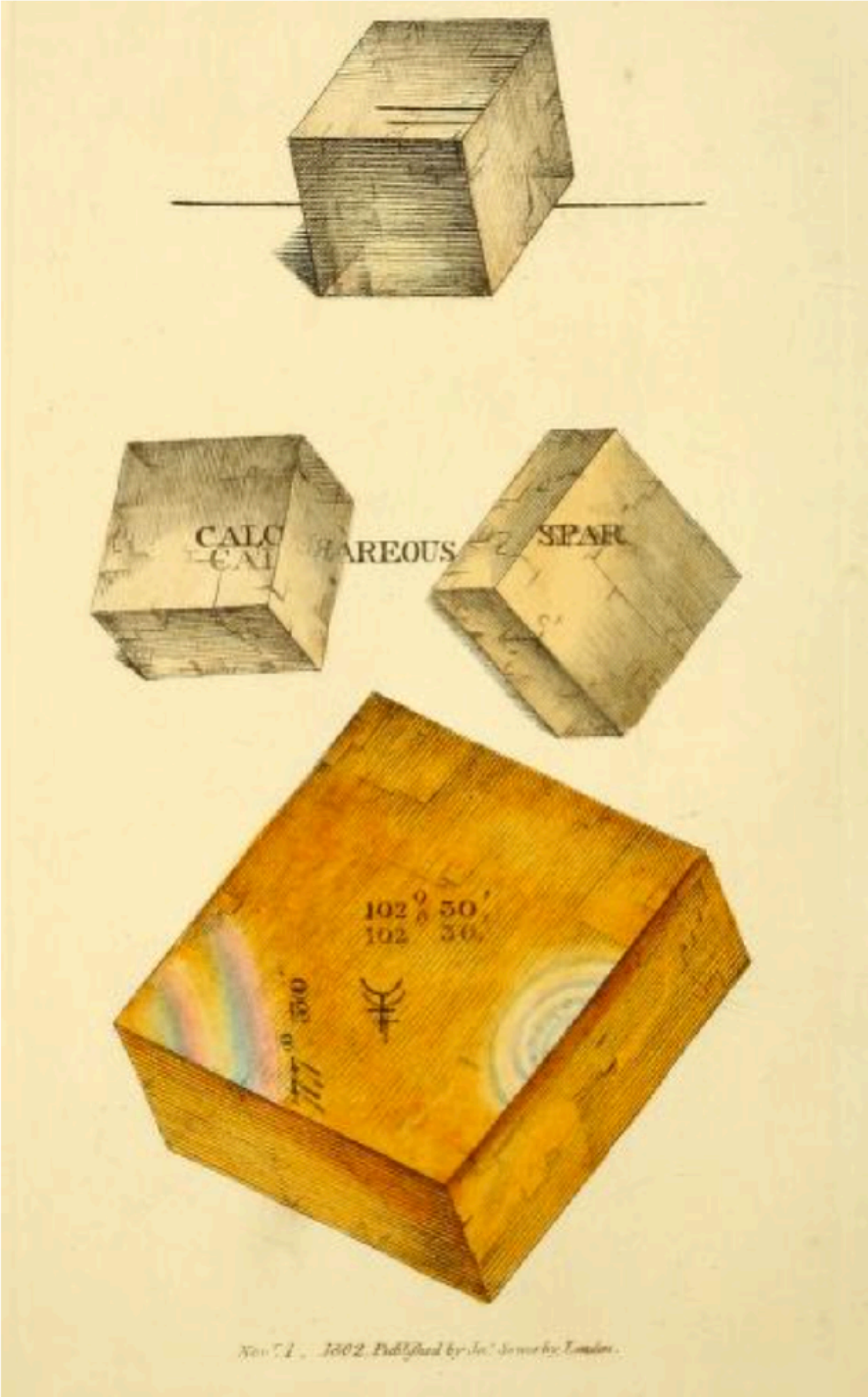

Figure 1.1: Sowerby, “Calx Carbonata.” In: *British Mineralogy*, vol. 1, Tab. II, November 1 1802.

Figure 1.2: Sowerby, “Calx Carbonata, var, metastatica.” In: *British Mineralogy*, vol. 1, Tab. XXXV, August 1 1803.

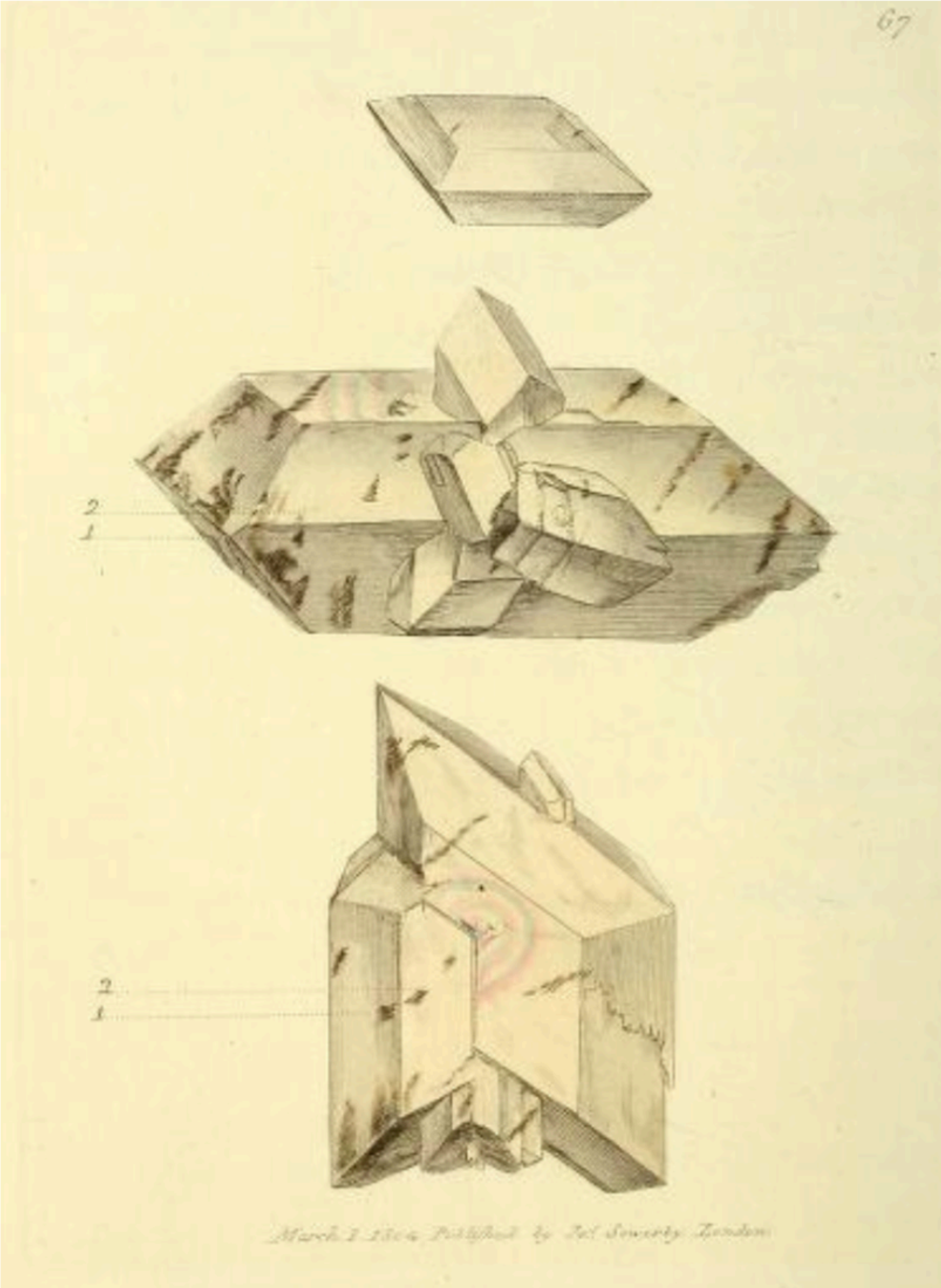

Figure 1.3: Sowerby, "Calx Sulphata." In: *British Mineralogy*, vol. 1, Tab. LXVII, March 1 1804.

> We may press together or open the lamina; which have been partially separated, of gypsum for instance, in order to produce the colours, either concentrically or otherwise, and this may be repeated, or we may allow them to be stationary for future use or practice, and to serve as one of our resources for a natural proof or example.[77]

Sowerby continues by describing the colours he observed while experimenting with a transparent mineral:

> I have a specimen of mica showing a minute opening or division of the laminae of about the eighth of an inch in diameter, having a yellow centre, which I place first; as it succeeds, in the increasing order of density, next to light. It is surrounded by light blue, passing through purplish brown to very dark, when, by degrees, it again passes into faint brown with a light margin, and then the stone appears to be close and solid surrounding it [see figure 1.4a]. In another part of the same specimen, I have a red centre, to which succeeds the yellow, and the yellow is succeeded by the blue, and the other rings succeed in due order as the first; A third flaw has blue in the centre, as in [figure 1.4c], with [figure 1.4b] the red, yellow, and the usual rings in the same succession.[78]

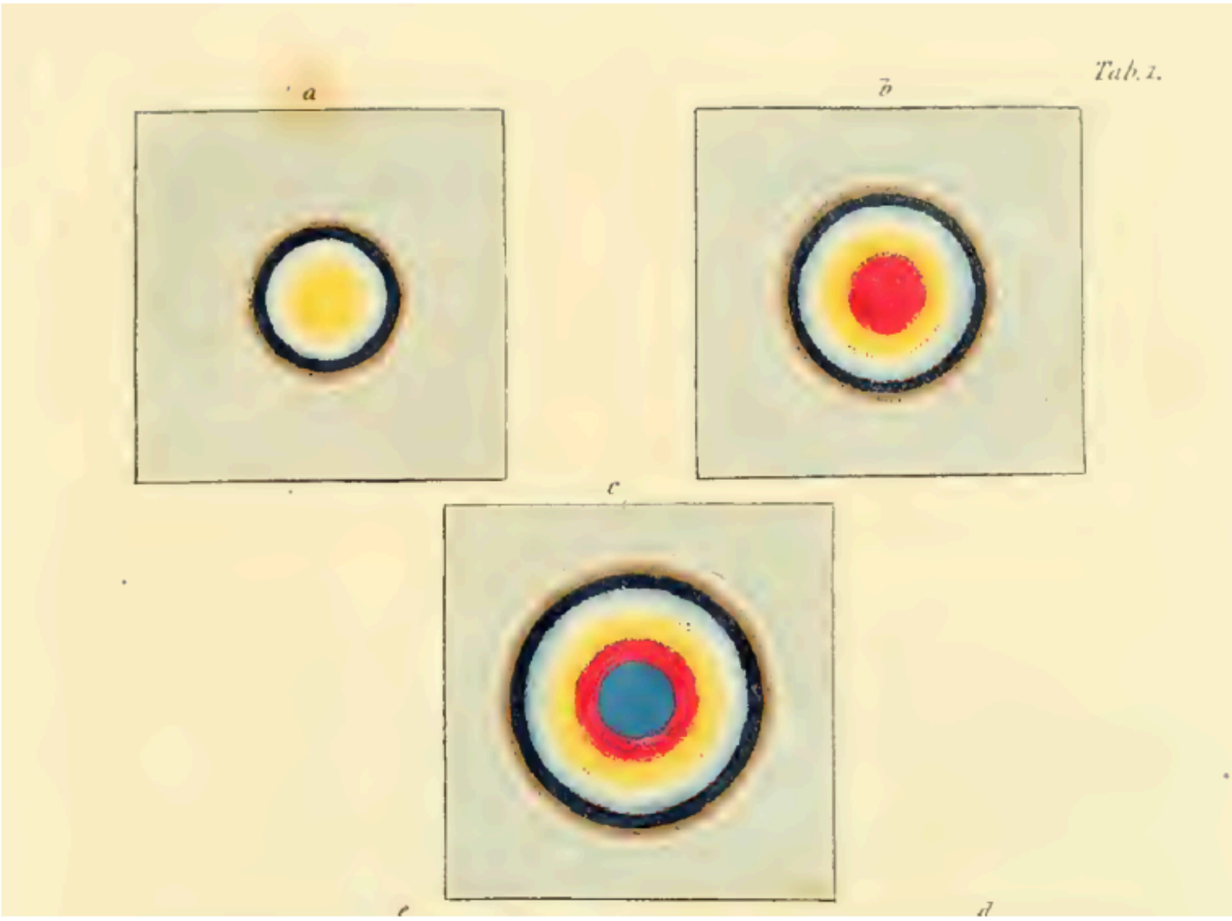

Figure 1.4: The upper three coloured circles as depicted by Sowerby, "Tab 1." In: *A New Elucidation of Colours*, 1809.

[77] Sowerby, *Elucidation*, p. 9.
[78] Sowerby, *Elucidation*, p. 9.

The colours Sowerby is able to perceive around the laminae are not identical at all places in the same mineral. However, Sowerby intends to find regularities in these observations nonetheless, in order to find proof for a generalisation towards a law of nature regarding colours as a result. As one can read in the quote above, Sowerby skilfully arranges his observations for this purpose: in the first example, he reports the colours he observed in one flaw, which contain the primary colours yellow and blue, but lack red, and do contain brown and purple. In the two following examples, however, he focusses on mentioning the primary colours red, yellow, and blue, and all other colours present receive minimal attention: they are not even named, and their presence is only referred to with the phrases “the other rings succeed in due order as the first,” and “the usual rings in the same succession.” In this way, he directs his reader to the generalising conclusion that he intends to proof with his observations:

> Blue, yellow, and red, omitting white as neuter, we find, are [the] three first colours […] as the tints come according to Nature, so we may conclude […] for the prismatic tints, however irregular they may appear, or seem confounded, are most perfectly and unerringly regular in their order.[79]

In the above example, Sowerby was convinced to have worked according to the standards a natural philosopher had to commit himself to: based on experiment and his observations thereof, Sowerby intends to have proven a general rule about the existence of three primary colours.[80] Furthermore, the information he presents and the conclusion he draws based on it show how strongly he adheres to the painterly notion that red, yellow and blue form the primary colours of nature.[81] And the other colours present are not dealt with until this point. However, in his next example, Sowerby will take on the task to explain how and why other colours are present in these rings as well.

Comparison with Newton’s experiments with coloured rings in the *Opticks*

Sowerby recalls with a comprehensibly paraphrased record of the *Opticks,* that Newton obtained very similar coloured rings in a different way: at the beginning of the second book of *Opticks*, Newton describes how he pressed two lenses, a convex and a plano-convex one, with the outward curved sides onto each other. At the point of contact, coloured rings were generated that were very similar to the ones present in the laminae of transparent minerals, although the order of the colours became inverted because Newton used convex shapes - where laminae can be regarded as concave shapes.[82]

After presenting these observations, however, Newton does not elaborate on the origin of the colours that are generated. Instead he quickly turns to the mathematisation of the phenomenon, measuring distances between the rings in order to find law-like regularities in their spacing. It is known that, although the *Opticks* central proposition is that white light can be separated in various coloured rays that are differently refrangible, Newton's main interests were these mathematical regularities regarding distances, and the colours themselves play only a minor

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[79] Sowerby, *Elucidation*, p. 13.
[80] For a more elaborate discussion about the standards for good practice for natural philosophers, see Lorraine Daston, and Peter Galison. *Objectivity*. Zone Books, 2010, p. 227.
[81] As Karin Leonhard has shown, these primary colours have long been regarded to be the sole domain of painters. Boyle “even apologises for his disciplinary encroachment “to meddle with the mixing of Pigments”, as this is “no inconsiderable part of the Painter’s Art””, “Flowering Colour — Still Life Painting and Baroque Colour Theory.” In: *Colour Histories. Science, Art, and Technology in the 17th and 18th Centuries*, edited by Friedrich Steinle and Magdalena Bushart. Berlin, Boston, De Gruyter, 2015, p. 289. See for an elaborate overview of the adoption of the three-primary doctrine by painters, and thereafter by natural philosophers Alan E. Shapiro, "Artists' colors and Newton's colors." *Isis* 85.4 (1994): 600-630.
[82] Sowerby, *Elucidation*, p. 12.

part throughout the book.[83] Savants in later decades criticised Newton for this mathematical focus.[84] The little importance that is ascribed to colours in the experiment can also be seen in modern reconstructions of Newton's experiments with these rings, that have received the name “Newton's rings”: they are mainly performed with sodium lamps. These lamps emit only one single colour of light, at a wavelength of 589 nm. Reconstructors claim that this is very convenient for the experiment: since most colours are eliminated in this way, the interval of bands is reduced to only two colours: black and the orange of the sodium light, making it easier to measure the distances compared to a multi-coloured example (see figures 1.5 and 1.6).[85] Newton himself also describes elaborately in the *Opticks* how one can create a ring pattern that shows only black and white rings, and how the distances in this case can be measured.[86]

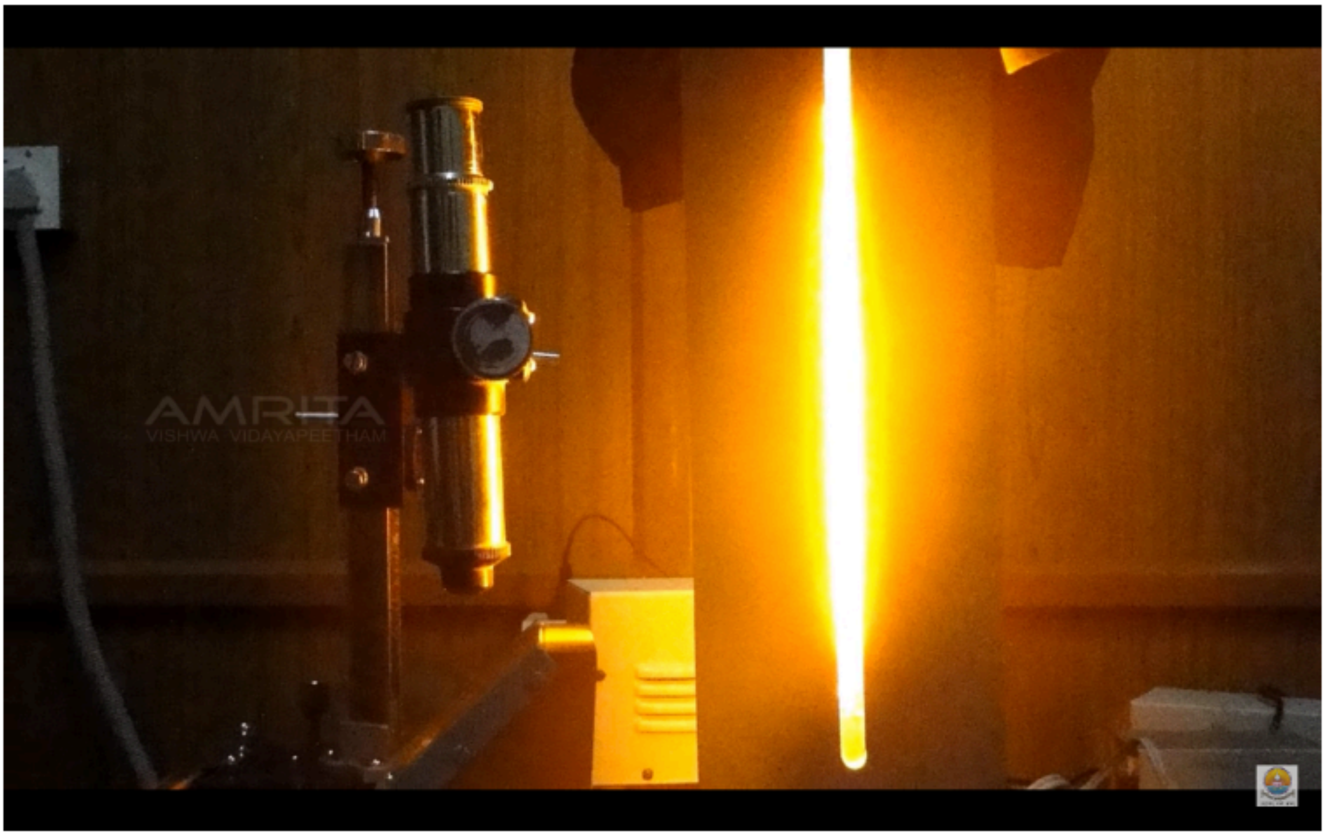

Figure 1.5: Experimental setup with an orange sodium lamp used by Amrita University to create Newton's Rings.

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[83] Hentschel, Klaus. "Verengte Sichtweise: Folgen der Newtonschen Optik für die Farbwahrnehmung bis ins 19. Jahrhundert." *Perspectives on Science* 4 (1996), p. 79; Ducheyne, Steffen, “Facing the Limits of Deductions from Phenomena: Newton’s Quest for a Mathematical-Demonstrative Optics,” *The Main Business of Natural Philosophy : Isaac Newton’s Natural-Philosophical Methodology*. Springer, 2012, p. 199-200; 205.
[84] Dijksterhuis, “Perceptions of Colours by Different Eyes”, In: Bushart, Magdalena, and Friedrich Steinle, editors. *Colour Histories: Science, Art, and Technology in the 17th and 18th Centuries*. De Gruyter, 2015, p. 35.
[85] See for instance “Newton's Rings - Amrita University” via https://www.youtube.com/watch?app=desktop&v=PU-SeNfIRcs or “Physics Lab Demo: Newton's Rings” via https://www.youtube.com/watch?app=desktop&v=ZqABNlA5d6I
[86] See for instance observations 3, 6 and 7 of the first part of the second book of *Opticks*, p. 196-197; 201-206.

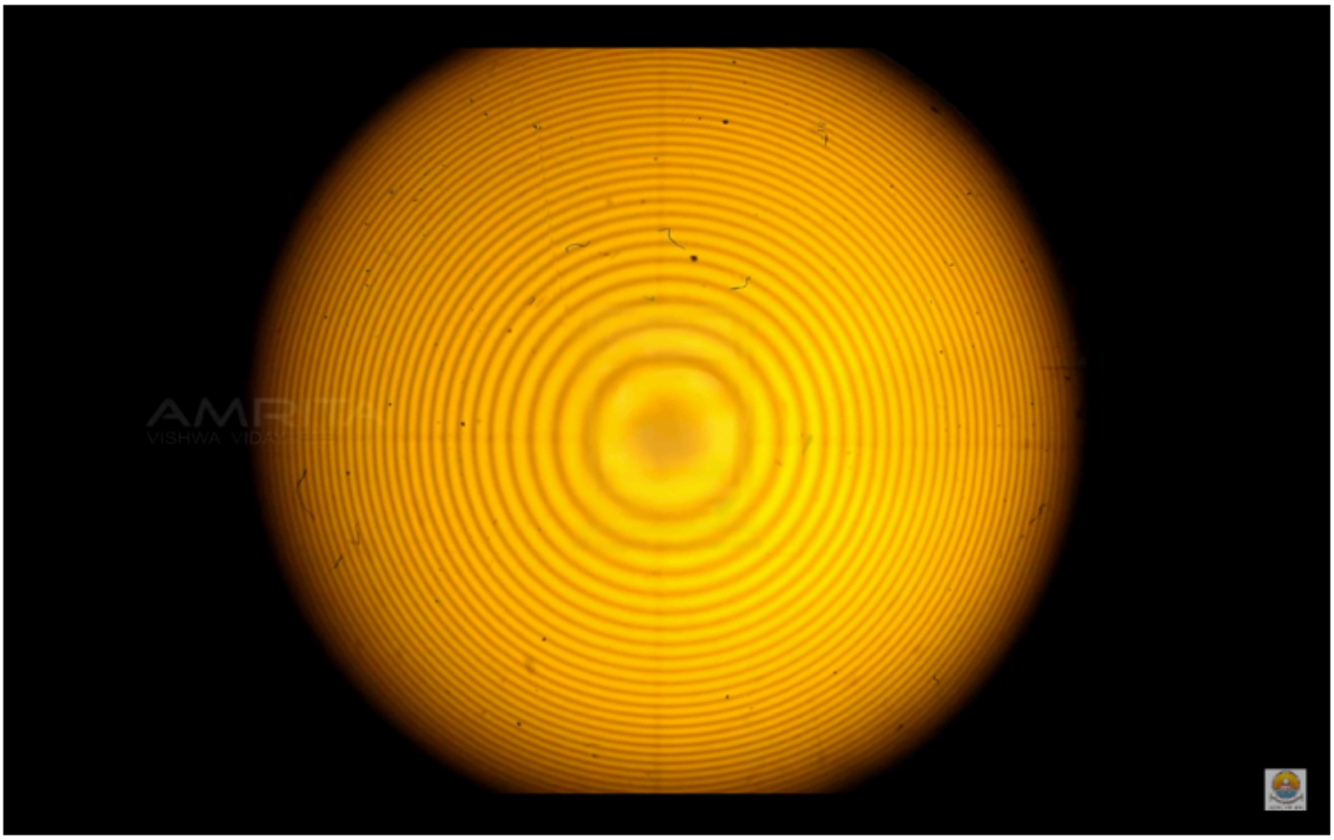

Figure 1.6: A reconstruction of Newton's Rings that shows no colours except the orange of the sodium light intercepted by dark rings.

Sowerby regrets Newton's focus on mathematisation of the phenomenon in the *Opticks*, since he suggests that important insights about colours are missed in this way:

> Sir Isaac Newton produced certain colours by the pressure of two glasses, and [...] naturally and truly [...] enumerated them without quite attaining the leading and true cause or principle of that arrangement, which he was so near discovering, and which would undoubtedly have been of the most essential consequence in such good hands.[87]

Between the lines, one can read how Sowerby states that he has been able to make discoveries that the great Newton overlooked. Sowerby claims to be able to explain the phenomena Newton could only enumerate without finding the general rules behind them, thus surpassing Newton's authority. Namely, in Sowerby's view this experiment with convex glasses proves the existence of exactly the same pattern as he himself had found when studying the coloured rings around the laminae of transparent minerals: red, yellow and blue. These are the first colours generated around the point of contact between the glasses, and therefore are the primary colours of nature.

In line with Newton, Sowerby divides the coloured rings that are generated from the contact point to the outside in groups of rings or "revelations". The first revelation contains, according to both Newton and Sowerby, only red, yellow and blue. Moving further outward, other colours start to appear as well:

> Next to the pellucid central spot, made by the contact of the glasses, succeeded blue, white, yellow and red. The next circuit immediately surrounding these consisted of violet, blue, green, yellow and red: all these were copious and vivid, except the green, which was very little in quantity, and seemed more faint and dilute than the other colours: of the other four, the violet or purple was the least in extent, and the blue less than the yellow or red.[88]

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[87] Sowerby, *Elucidation*, p. 10.
[88] Sowerby, *Elucidation*, p. 11.

Sowerby in his *Elucidation* expresses his astonishment that Newton overlooked the clear way in which nature presented that red, yellow and blue are the fundamental colours, and that the other colours only start appearing from the second circuit onwards, making them secondary in nature. Furthermore, Sowerby mentions the breath of the various coloured rings, not because he intends to measure and tabulate them, but because in his theory their thickness indicates the extent to which the primary colours overlap in this second circuit, and therefore create the newly revealed colours:

> It is perhaps now to be wondered that sir Isaac Newton did not take more particular notice […] of the three primitive tints mixing as the circles became narrower, which was the cause of the green in the […] ring.[89]

According to Sowerby, the green is of little quantity in the second ring, because the yellow and blue only slightly overlap to create this mixed colour. Furthermore, the violet or purple was also little in quantity, since it was only created by the overlap between the blue and red. And lastly, one could observe that the blue band was smaller than the yellow and red ones, since blue overlapped with both to create the green and purple, while no orange could be discerned yet, leaving the yellow and red bands intact to a larger extent.

When rings begin to overlap, explains Sowerby, one will obtain

> the order in which he so naturally found the colours in the circles.—First, the three primitives and the seven prismatic tints naturally mixed from them, which I wish he had been aware of, as it would have accounted for the other rings or revolutions.[90]

Comparison with Goethe's colour observations

Goethe also bases his observations on the colours generated by pressing two convex plates of glass together. However, he indicates that these phenomena can also be observed in laminae of transparent minerals, and further that

> nature often exhibits the same phenomena in split rock crystals. This appearance, again, frequently displays itself in the mineral world in those kinds of stone which by nature have a tendency to exfoliate. These original lamellæ are, it is true, so intimately united, that stones of this kind appear altogether transparent and colourless, yet, the internal layers become separated, from various accidental causes, without altogether destroying the contact: thus the appearance, which is now familiar to us by the foregoing description, often occurs in nature, particularly in calcareous spars; the specularis, adularia, and other minerals of similar structure.[91]

Goethe, in this instance, names the same colours as Sowerby and Newton described. However, the different order in which he mentions them is significant, since it shows his underlying assumptions about the generation of these colours:

> The centre is colourless; where the glasses are, so to speak, united in one by the strongest pressure, a dark grey point appears with a silver white space round it: then follow, in decreasing distances, various insulated rings, all consisting of three colours, which are in immediate contact with each other. Each of these rings, of which perhaps three or four might be counted, is yellow on the inner side, blue on the outer, and red in the centre.[92]

Instead of naming the colours in their successive order, Goethe first mentions the two outer colours, and only thereafter names the red. This is in line with Goethe's ideas about primary

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[89] Sowerby, *Elucidation*, p. 11-12.

[90] Sowerby, *Elucidation*, p. 12.

[91] I have used the English translation of the *Farbenlehre* made by Charles Eastlake in 1840, adjusting his translations according to my own views where I regarded that insightful. Goethe, p. 186; par. 448-449.

[92] Goethe, p. 179-180; par. 433.

colours. According to him, painters may base their practice on three primary colours, but for philosophers two colours do suffice:

> the painter is justified in assuming that there are *three* primitive colours from which he combines all the others. The natural philosopher, on the other hand, assumes only *two* elementary colours, from which he, in like manner, developes [sic] and combines the rest.[93]
> Blue and yellow do not admit of increased intensity without presently exhibiting a new appearance in addition to their own. Each colour, in its lightest state, is a dark; if condensed it must become darker, but this effect no sooner takes place than the hue assumes an appearance which we designate by the word reddish.[94]

For this reason, Goethe does not regard red to be a primary colour, but he states that the red band visible in between the yellow and blue bands is generated out of the blue band: "From the centre of the blue a red appears, which is thus, in all cases, bounded on the outside by its blue edge."[95]

In order to understand this divide Goethe creates between painters and natural philosophers, and the amount of primary colours they needed, it is enlightening to take into account the kinds of objects both groups studied as objects of their profession. Painters, who worked with pigments, would indeed need yellow, blue *and* red, in order to create other colours. Without red, no oranges and purples can be formed. A natural philosopher like Goethe, on the other hand, did not mix pigments, but observed how colours developed in natural processes. Observing the sky, one could see that the light blue colour it displayed at daytime would gradually "intensify" via a purple or orange, when the sun approached the earth closer and closer, to at last turn into an intense red at sunset.[96] In a similar way, yellow pears would be influenced by the heat of the sun, that, according to classical Greek thought, would boil the juices within the pear. The back side of the pear that was barely touched by the sun, would retain its yellow colour. While the side of the pear that faced the sun would receive so much heat, that it would boil and concentrate the juices within, turning its outer colour from yellow into its intensified form: red.[97]

With this observational background of Goethe in mind, it also becomes easier to understand the implicit assumptions underlying his descriptions of the outermost rings that become visible at the intersections between plates of glass, or in the laminae of minerals. Sowerby, as we have seen above, regarded green not as a primary colour, but as a secondary colour that generated when blue and yellow bands are allowed so little space in the outer rings, that they start to overlap. Goethe, in a similar way, explains that the outermost circles are compressed: "The rings which are farthest from the centre are always nearer together: they are composed of red and green without a perceptible white space between them."[98] Furthermore, Goethe regards green to be a mixture of blue and yellow bands: "Yellow and blue edges mix together, thus producing a beautiful green. The red, however, of each circle, remains pure and untouched; hence the whole series is composed of these two colours."[99] In Goethe's view there are two ways in which blue and yellow can touch: when they overlap, they will form a green. But when their intensified sides are connected, this intensification is brought to a climax, generating the most perfect red one has ever seen: "when the two opposites, yellow and blue, are united by

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[93] Goethe, p. 279; par. 704.
[94] Goethe, p. 277; par. 699.
[95] Goethe, p. 181; par. 436.
[96] Karin Leonhard, "Flowering Colour — Still Life Painting and Baroque Colour Theory." In: Bushart, Magdalena, and Friedrich Steinle, editors. *Colour Histories: Science, Art, and Technology in the 17th and 18th Centuries*. De Gruyter, 2015, p. 269-270; 276.
[97] This idea originates with Julius Pollux, and was later adopted by Aristotelians. About the indebtedness of Aristotelians to Pollux, see Leonhard p. 266. Goethe himself describes this idea of reddening fruit based on the boiling of its juices extensively in the Historical part of his *Farbenlehre*, see "Von Verånderung der Farben, an den Pflanzen, durch organiſche Kochung," par. 39-62.
[98] Goethe, p. 179-180; par. 433.
[99] Goethe, p. 180-181; par. 435.

their red extremities, pure red appears: the green, on the other hand, as in prismatic experiments, when yellow and blue touch."[100]

Although Sowerby and Goethe regard green to be generated in a similar way, Goethe's observations of the red bands are in strong contrast with the descriptions of the red bands provided by Sowerby and Newton. According to the latter two, the idea that bands start to overlap in the outermost rings of this phenomenon, is not only at play for the green, but is equally applicable to the red bands. The red bands become dirty tinged because the red is blurred by other coloured rings that become superimposed over it in the limited space allowed in the outermost revelations, and not, as Goethe claimed, "pure and untouched".

Based on my reconstructions of the phenomenon, I remain indecisive about the exact colours that are observable. Pressing two pieces of glass together, the colours I can observe are very faint and the circles extremely small. So, I now understand why most reconstructors use very powerful microscopes to study these rings. Furthermore, the static depictions of the observable rings by Sowerby, Newton and Goethe turn out to be deceptive: because the colours are generated at a point of contact, their position changes constantly and rapidly. No band will stay in position for even a second, and the colours of the bands change from second to second as well. I was unable to capture them myself, but some stills I captured from a reconstruction video by Hazhar Ghaderi are enlightening in this respect (see figure 1.7).[101]

It is known that Newton also attempted to analyse the colours of soap bubbles, and describes elaborately in his *Opticks* how he tried to keep them in place.[102] In my opinion, the colours present at the contact points between glasses are just as fleeting, and therefore hardly analysable.

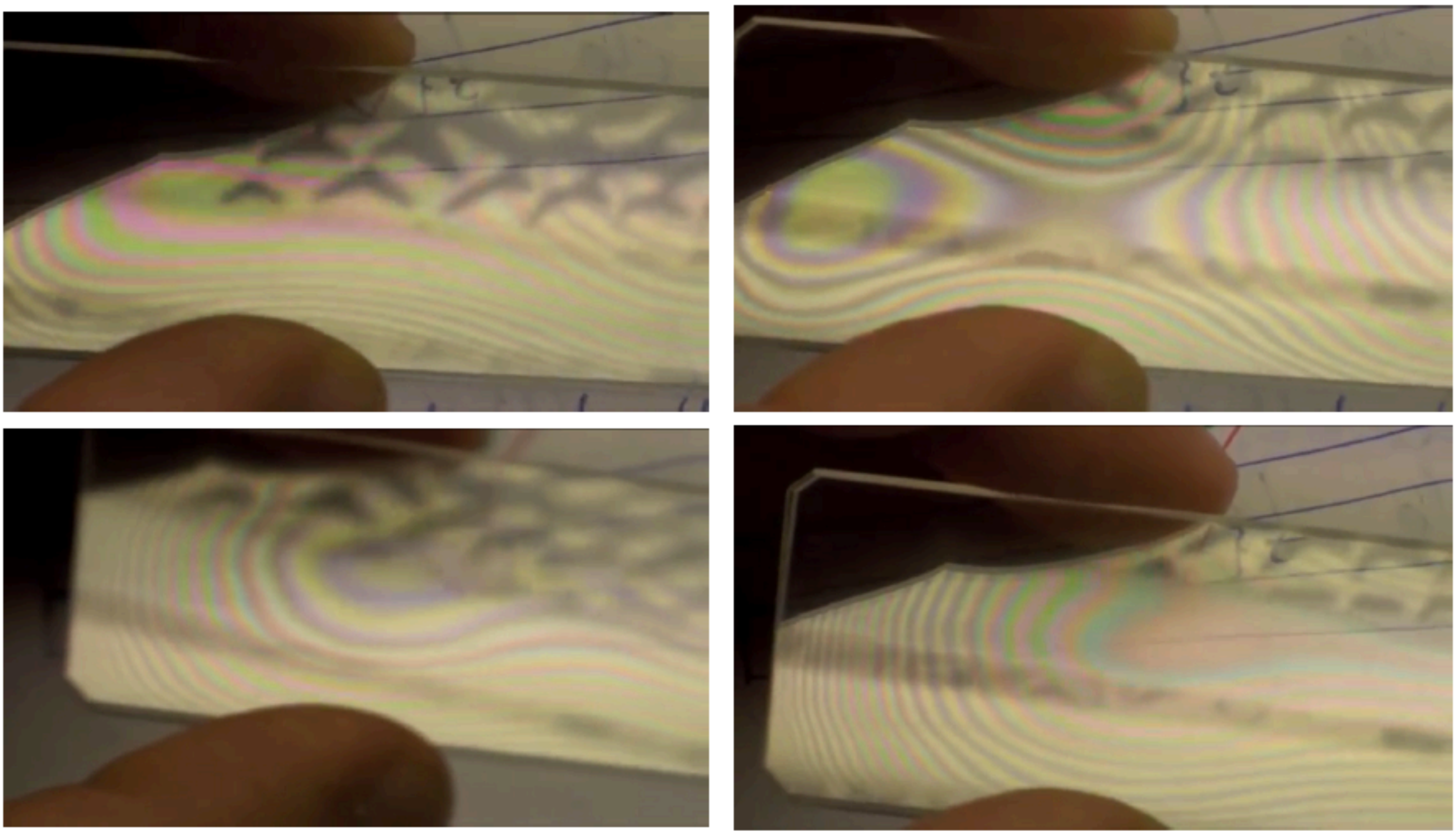

Figure 1.7: Four stills from a reconstruction of coloured rings, generated by pressing two glass plates together. The stills show that the position and colour of the rings changes from second to second. Reconstruction by Hazhar Ghaderi.

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[100] Goethe, p. 188; par. 452.

[101] Hazhar Ghaderi, "Newton's rings and interference." Accessed via https://www.youtube.com/watch?v=IzI0oo7KSUo 25-02-2024.

[102] Newton, *Opticks*, fourth edition, p. 214-221; Obs. 17-20.

The unnoticed mixture of light: brown

As we could read in Sowerby's first descriptions of the colours present in transparent minerals above, he remarked that brown rings are present, and that they are observed most often at the outermost edges of the coloured rings. Neither Goethe, nor Newton, remarked the appearance of browns in these phenomena. Sowerby points this out: "Browns have scarcely, if at all, been considered by authors on this subject."[103]

When using a prism, according to Newton's theory, all prismatic colours mixed together will create the illusion of white light. It had often been stressed that the pigments painters use mix differently, and create a brown or black when they are combined.[104] This idea of a strong difference between painters colours and prismatic colours does not exist in Sowerby's mind. When we look at his observations about how light can create colours in transparent minerals, we will be able to understand why.

Sowerby stresses that before the series of colours generated by light in transparent minerals ends in perfect whiteness at the extreme edge of the rings, one can first perceive brown.[105] Browns, according to Sowerby, are generated when yellow, blue and red together overlap. Therefore, browns will only become visible because the outermost bands are allowed so little space, that the green and "dirtyish red" bands start to overlap as well: "It was therefore required to contrive that the yellow, red and blue rays should pass among each other, for the production of browns or ternaries."[106] He remarks that bringing these types of coloured rays together, is "something like the mixing of material colours." Thereby his observations and resulting theory about the creation of colours are meant to prove that the mixing of light and the mixing of pigments can create the same effects. This is notably not only a theoretical attempt to harmonise ideas about colours from painters and natural philosophers, but Sowerby also shows that painters will be able to discard the use of pigments for their practice and fully rely on colours generated by light - since even the browns of their palette can be generated when rays of light are mixed in the right proportions.

Prismatic experiments as building blocks for colour theories

After explaining what Sowerby regards to be the primary colours in nature, and how they can mix to create all other colours, Sowerby's next step towards the creation of a standardised communication method for colours, is to move away from just observing what nature creates relatively spontaneously, and take the creation of nature's colours literally into his own hands: "I therefore took the usual three-sided prism, and was highly gratified by observing [when looking at the face of the prism] the three primitive tints, a fine yellow, a rich red, and a light blue."[107] Besides looking at the colours in the surface of the prism, Sowerby also describes that one can project these colours on objects surrounding the prism:

> At the same time as the above, may be seen refracted immediately from the sun's most brilliant rays, upon any object within a few inches, a fine image of the prism bordered lengthwise, by the same three tints: [see figure 1.8].[108]

Observing these projected colours is of great value to Sowerby, since "[t]his shows the primitive tints on a larger scale, and will therefore give a fuller explanation of the whole."[109]

According to Sowerby, four distinct bands of colour can be perceived in such a projection: "Thus the middle I call white, as the more direct light, the yellow is below it, the red lowest, and the blue on the uppermost or opposite side."[110] Omitting "the white as a neuter", this observation again proves that the three primary colours of painters are the first colours nature creates out of light.[111]

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103 Sowerby, *Elucidation*, p. 9.
104 Dijksterhuis, p. 28.
105 Sowerby, *Elucidation*, p. 11.
106 Sowerby, *Elucidation*, p. 20.
107 Sowerby, *Elucidation*, p. 16.
108 Sowerby, *Elucidation*, p. 16.
109 Sowerby, *Elucidation*, p. 16.
110 Sowerby, *Elucidation*, p. 16.
111 Sowerby, *Elucidation*, p. 13.

Figure 1.8: Sowerby's depiction of the colours one should see at the borders of a projection of the sun's rays through a prism. Lowest figure on Sowerby's "Tab 2." In: *A New Elucidation of Colours*, 1809.

As with the coloured rings in transparent minerals, with a prism secondary colours can be created as well, although in this case it requires active handling of the prism by the experimenter:

> and I found, by turning the prism […] The rays, as they become more oblique, spread over each other, the yellow over the white to the blue forms green, while the blue on the darker side is changed into violet and indigo. The red, by the same motion, passes over some of the yellow spreading into orange, and thus are formed the regular seven prismatic tints or spectrum.[112]

In Newton's view, overlap between colours also forms the key to understanding the generation of colours by a prism under the condition that one does not analyse a very smal ray of light in a darkened chamber, but a very broad ray of light. When the ray of light led through the prism is as broad or almost as broad as the prism itself, as Newton used for his experiment described in *PROP.* VIII. Prob. III, it will create similar phenomena as when a prism is held in open daylight - as Sowerby did. However, Newton's ideas about the role of overlap of different rays to create the colours one perceives in this experiment, is almost the exact opposite of Sowerby's explanation.

Figure 1.9 shows a schematic depiction of the experimental setup Newton used for this experiment. ABC represents a prism, that is illuminated by a broad ray of light shining through the hole Fφ. There are two positions sketched for projection of the rays on papers: at the largest distance mn and the closer position MN. When the generated colours are cast on a paper (mn) held at a large distance, according to Newton because of the different refrangibility of various rays of light, this will create a spectrum similar to the one created when a small beam of light is shown on a prism - as in the experiments he is most well known for. With the prism oriented with its base upward and its tip pointing downward, as in this experiment, at the top of the paper mn, the most refrangible rays will be cast, showing a violet colour. Leading ones eye downwards, one will be able to perceive a continuous spectrum that starts with this violet (PQ), under which follow indigo (QR), blue (RS), green (RT), yellow (Sρ), orange (Tσ) and which ends with the least refrangible red (στ) rays. According to Newton, this situation shows all the homogeneal colours: the colours of the spectrum are all present in their unmixed state.[113] Notably Newton also mentions green and orange as homogeneal colours.

The green in this spectrum, as one can see in this schematic depiction, is in Newton's view a compounded green, and not solely a homogeneal green: for not only homogeneal rays are present at this point, but blue and yellow rays as well, and these three types of rays overlap, creating an impression of green. In this regard, Newton's and Sowerby's ideas seem to be in accord: green can be made by mixing yellow and blue. But whereas green is solely a mixing colour in Sowerby's view, it also exists as a homogeneal type of rays in Newton's theory.[114]

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112 Sowerby, *Elucidation*, p. 16.
113 Newton, *Opticks*, fourth edition, p. 161; 164.
114 Newton, p. 164.

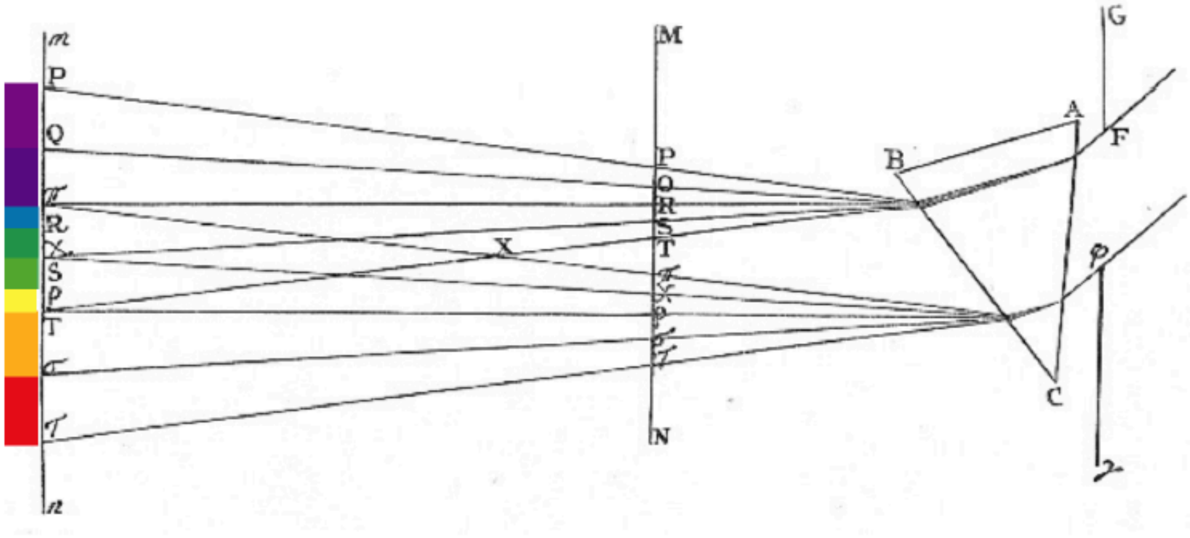

Figure 1.9: Newton's fig. 12, showing a schematic depiction of the experiment executed in Book 1, PART II, PROP. VIII. Prob. III. Newton, *Opticks*, 4th edition. As a reading-aid I added a band depicting my interpretation of the colours Newton describes to be visible at the far left.

When the paper is moved closer to the prism, at the distance of the paper MN in the figure, the observed spectrum of colours will be different: the green disappears, and instead a broad white band appears in the centre - just as Sowerby described.[115] However, in Newton's description the colours bordering the white, as well as the explanation of what is visible in this situation, are markedly different.

According to Newton, the colours of the spectrum are differently refrangible, and therefore will be projected at slightly different positions on the paper. As on the paper mn, the violet is refracted the least, and will therefore be projected highest on the paper MN. But since the ray of light led through the prism is very broad, the band of violet will be just as broad (spanning the distance Pπ in the figure). The least refrangible red rays will cover the distance Tτ. Furthermore, the other colours generated by refraction of the white light will be cast:

> the middle sort between the indigo-making and blue-making Rays upon the Space Qχ, the middle sort of the green-making Rays upon the Space R, the middle sort between the yellow-making and orange-making Rays upon the Space Sσ, and other intermediate sorts upon intermediate Spaces.[116]

Because in the centre of the paper MN, all the bands of the different colours overlap

> the distance between them Tπ will be illuminated by all the sorts of Rays in that proportion to one another which they have at their very first coming out of the Prism, and consequently be white. But the Spaces PT and πτ on either hand, will not be illuminated by them all, and therefore will appear coloured. And particularly at P, where the outmost violet-making Rays fall alone, the Colour must be the deepest violet.[117]

Contrary to Sowerby's argument that this experiment proofs the existence of the three painters primaries blue, yellow and red, Newton in this experiment observes also violet to be at the top of the white band, and not only blue. Furthermore, he discerns even more colours above the white centre, that all are the result of the broad bands of colour overlapping:

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115 Newton, p. 162.
116 Newton, p. 161-162.
117 Newton, p. 162.

> At Q where the violet-making and indigo-making Rays are mixed, it must be a violet inclining much to indigo. At R where the violet-making, indigo-making, blue-making, and one half of the green-making Rays are mixed, their Colours must […] compound a middle Colour between indigo and blue. At S where all the Rays are mixed, except the red-making and orange-making, their Colours ought by the same Rule to compound a faint blue, verging more to green than indigo. And in the progress from S to T, this blue will grow more and more faint and dilute, till at T, where all the Colours begin to be mixed, it ends in whiteness.[118]

Newton does not only perceive a much larger number of colours at this part of the spectrum, but he also argues that the white (that Sowerby ignored since to him it was only a neuter) is the part of the spectrum where the coloured bands are mixed to the largest extent. Because of this overlap of bands, the homogeneal green that one would perceive at a larger distance is, according to Newton, entirely covered by all other broad bands of colour at this point; and thereby the green is not visible anymore. Green in his view is not the result of mixing colours, but it is a primary spectral colour that can be made invisible when mixed with other colours.

At the other side of the white, mixing colours will become observable to the viewer again. According to Newton, this can be explained by keeping the breath of the coloured bands in mind. Although the bands are very broad, there still is a limit to their length: the length of the prism in which a colour can be refracted. Therefore, there will be a point as low on the paper that the violet rays cannot reach it anymore. Therefore, a mix of all colours except violet will be visible at this spot. One by one, the rays will reach the limit of their breath, and therefore will not take part in the mix of colours anymore, until at the bottom of the spectrum only the least refrangible red rays are still visible. Or, describing the perceivable (mixtures of) colours from the bottom upwards in Newton's own words:

> So again, on the other side of the white at τ, where the least refrangible or utmost red-making Rays are alone, the Colour must be the deepest red. At σ the mixture of red and orange will compound a red inclining to orange. At ρ the mixture of red, orange, yellow, and one half of the green must compound a middle Colour between orange and yellow. At χ the mixture of all Colours but violet and indigo will compound a faint yellow, verging more to green than to orange. And this yellow will grow more faint and dilute continually in its progress from χ to π, where by a mixture of all sorts of Rays it will become white.[119]

Also at this part of the white band, Newton perceives many more tints of colours than the demarcated bands of red and yellow Sowerby claimed to see. In sum, from the top to the bottom on the paper MN in this experiment Newton describes to see: "the Colours in order from P to τ ought to be violet, indigo, blue, very faint green, white, faint yellow, orange, red."[120]

One of the questions that arose while I was reconstructing Sowerby's experiments, was why the red and yellow are present at one side of the white, and blue at the other side. Sowerby, namely, does not provide any explanation why his three primary colours were separated in a group of two colours at one side, and another colour at the other side of what he named "the white neuter".[121]

Reading Newton's theory, this separation is - as we have seen above - easily explained: the white is caused by overlapping coloured bands, while at the edges of the spectrum these coloured bands overlap only partially, in an arrangement similar to a rainbow. At the bottom of the spectrum the non-overlapping bottom of one rainbow is visible, showing red, orange and yellow, and at the top the non-overlapping top of what looks like another rainbow is present, showing the blue, indigo and violet part of the spectrum. Only green is invisible, because this part of the spectrum is never present in a non-overlapping position. In Newton's view, the white is not a neuter, but a mixture of various colours.

Goethe provides a very different explanation for the separation of colours at both sides of the white part of the prismatic projection. In Goethe's view of nature, many binary oppositions are present, and they are related to each other. The binary hot - cold is connected to the dichotomy yellow - blue. Because these opposite colours are in conflict with each other, they appear

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[118] Newton, p. 162.
[119] Newton, p. 164.
[120] Newton, p. 164.
[121] Sowerby, *Elucidation*, p. 13.

separated at two different borders of the spectrum. Since, in his view, red is intensified yellow or blue, a yellow-red and blue-red band are present at the extremities of these borders. According to his observations, a reddish colour is therefore present at both sides of the divide, although tinged differently because it originates from a different base colour:

> On one side, in the direction in which the luminous image is moved, a violet border advances on the dark, a narrower blue edge remains next the outline of the image. On the opposite side a yellow border advances into the light of the image itself, and a yellow-red edge remains at the outline.[122]

According to Goethe, four colours are visible in this spectrum: violet, blue, yellow and yellow-red (his name for orange; see figure 1.10). Although Goethe is generally regarded to be a better observer compared to Newton, since he perceived and described colour observations in more detail, he does not mention indigo to be present between the blue and the violet. And since the purest red according to Goethe only becomes visible when the intensified parts of the yellow and blue meet - which is not the case when they are placed at the extremities of the spectrum - he does not regard a full red to be present either.

It is also worth noting the difference in perspective taken by Sowerby in comparison to Newton and Goethe. Sowerby depicts the phenomenon as he himself observes it: he shows the reader an image of the spectrum when one looks straight at the wall. Newton and Goethe, on the other hand, approach the experiment as distant observers: they do not show what the experimenter him- or herself would see, but both show the reader the experimental setup from the side. In this way, the reader gains insight in the placement of the equipment to conduct the experiment – knowledge about the experiment that Sowerby's depiction does not convey. But in Newton's depiction the information about the direct outcome with regard to colours is lost completely. It requires considerable effort from the reader to deduce the perceivable colours from his theoretical explanation. Goethe decides to combine both types of visualisation in his figure: he shows the experimental setup from the side, but he adds inserts with a small depiction of the coloured bands one would observe from a frontal perspective below.

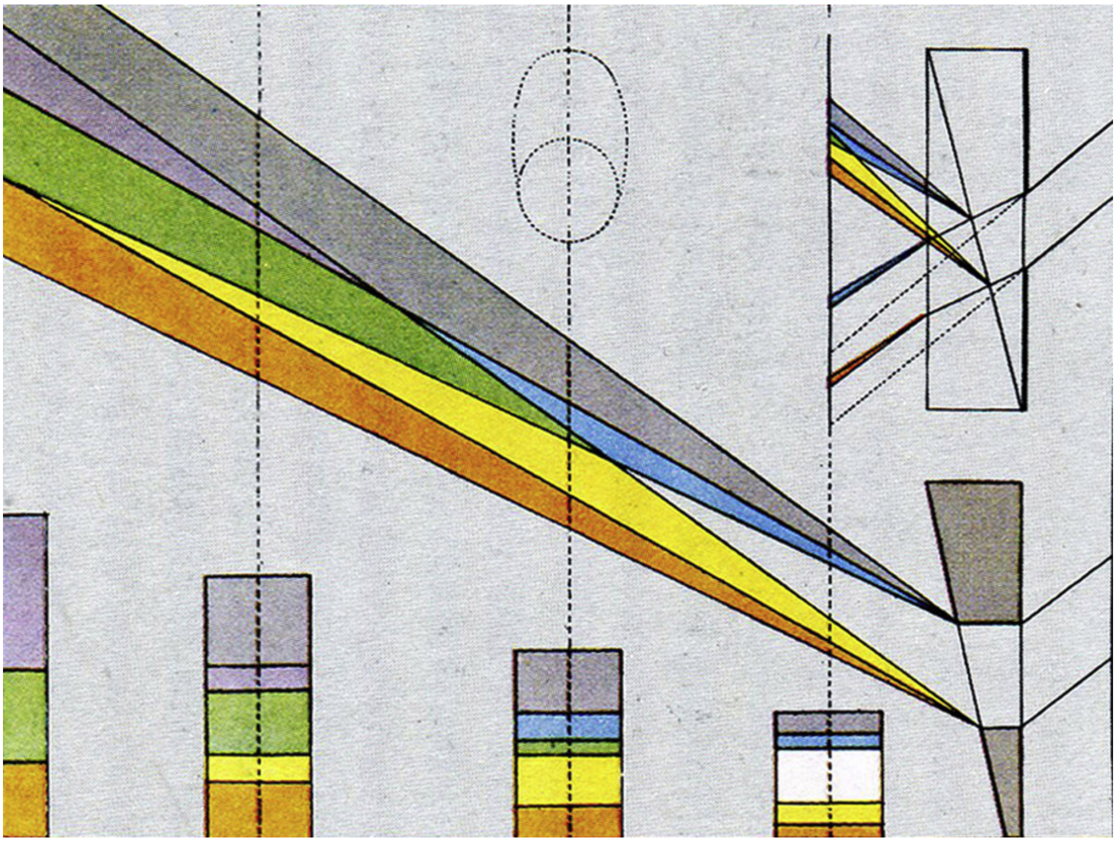

Figure 1.10: Schematic depiction of the colours one should perceive according to Goethe. Plate IV of "Zur Farbenlehre" (1810) Public domain, Gutenberg Library.

[122] Goethe, p. 135, par. 328.

Conclusion

In this chapter, I have shown that the three painters primaries, red, yellow and blue, formed the principal building blocks of Sowerby's theory, together with the idea that all other colours could be created by mixing them. Comparing Sowerby's observations with Newton's and Goethe's in similar experiments, we could see that Sowerby was convinced that his observations in transparent minerals and experiments with prisms proved the existence of these, and only these, three colours as the primary colours of nature. It also became clear how the other two experimenters based on their different theories perceived many more colours, when analysing the coloured spectrum projected on a wall. Furthermore, once other colours appeared, as was the case in the second and higher revelations in transparent minerals, Sowerby explained them as proof of the formation of mixing colours, and he classified them as secondary, or even tertiary colours. He regretted that the natural philosopher Newton had not remarked what could easily be explained with his own colour mixing theory. Thereby, Sowerby showed that the idea of the painters primaries was well-suited for explaining phenomena outside of the painters domain: in the realm of natural philosophers who generated colours in their experiments.

Goethe argued that the amount of primary colours painters and natural philosophers need is different, since both groups work with respectively different materials and study different phenomena. In this way, he created a firm barrier between them. Sowerby instead used observations of natural phenomena - the domain of natural philosophers - to argue for the universal visibility of the three painters primaries red, yellow and blue. In his view, these primary colours are not only the ingredients with which painters could create their entire palette of colours. They are also the building blocks observable amongst the colours nature presented to natural philosophers. In this way, Sowerby not only combined ideas about colour he had been introduced to during his own activities in both fields of knowledge, but he also tried to convince others of the perfect overlap between ideas about prismatic colours and material colours, and thus the possibility to merge studies (experiments, observations and explanations) from both fields in one overarching theory. Since in Sowerby's view the same three primaries formed the basis for both material colours and prismatic colours, and these primaries therefore also followed the same mixing rules, Sowerby could furthermore argue that painters could easily do away with material colours in the form of unstable and unreliable pigments, and adopt a method based on prismatic colours instead.

Studying the preliminary observations and experiments Sowerby described in his *Elucidation* has revealed Sowerby's theoretical assumptions about the colours central to the chromatomatometer: red, yellow and blue. The analysis also revealed how he imagines these primaries would mix to form secondary and tertiary colours. Furthermore, the analysis has made it possible to understand the function of Sowerby's description of observations and experiments that at first glance might not seem to be related to the usage of his chromatometer: Sowerby presented these in order to convince the reader that the transfer from pigments to his chromatometer method, based on colours generated in a prism, would provide exactly the same colours, only in a much more stable and reliable form.

To be able to perform and comprehend Sowerby's method, more is needed than an understanding of his ideas about red, yellow and blue, and the colours that can be generated by mixing them. In order to understand the theoretical assumptions underlying Sowerby's chromatometer method in its entirety, it is essential to investigate his ideas about black and white, and how these are implemented in his method. On top of that, Sowerby's primary and secondary colours could not be generated without the use of a light dispersing material. In chapter two, these additional visual and material aspects of Sowerby's method shall be addressed.

Chapter two: Mixing light with materials

What is the status of black and white in the realm of colours?

> We have, as it were, white as the first beginning of colours, and brown to black the termination of them to our senses. We shall find in the sequel that these include all colours, and that a certain position or arrangement will make them evident, with the most beautiful order and unerring regularity.[123]

So explains Sowerby in the first lines of his *Elucidation*. Viewing white as the beginning of the series of colours, and black as its terminator, is an idea ascribed to Aristotle. In Aristotle's view, all other colours could be created by mixing different proportions of black and white.[124] Around the turn of the eighteenth century, Newton developed his alternative theory about the generation of colours out of light. Newton had a fundamentally different idea about the roles of black and white, as was already touched upon in chapter one. In his view, all spectral colours together form white, and this can be revealed when holding a prism in a beam of white light: the difference in refrangibility of the coloured rays will cause the white to break down into its components, and reveal its colours. Black in his theory solely is the absence of light and colour. This "New Theory of light and colours" gained adherence during the eighteenth century, and had become a strong competitor to the Aristotelian doctrine about colours at the beginning of the nineteenth century. In our current historiography about colour theories, ideas about the generation of colours and the role of black and white in their generation are generally divided into two groups: the modification theories, that in line with Aristotle believe that colours are created by mixing white and black, and the "New Theory" of Newton.[125]

We read in chapter one that Sowerby had a firm belief in the existence of the three primary colours red, yellow and blue, instead of Newton's continuous spectrum, also when he generated colours with a prism. Furthermore, analysing the water-metaphor, we saw that Sowerby introduced another part of Aristoteles' theory at the opening of his *Elucidation*. However, it became clear that Sowerby only referred to Aristotelian thought to show that the ideas of an authority who had been adhered to for centuries, could be unmasked as faulty by modern discoveries. Tracing how Sowerby develops his ideas about colours further in his *Elucidation*, it will become clear that the role black and white play in his theory differ greatly from these of Aristotle: to Sowerby they evoke the "real" colours one can perceive by looking at his chromatometer through a prism. Although Sowerby adopts a few premisses of Newton's theory of light and colours, I shall argue that Sowerby's ideas about the role of black and white for the generation of colours strongly deviate from Newton's theory as well. Studying Sowerby's ideas about how light and darkness, or black and white generate colours will show that not just two groups of colour theories were available at the beginning of the nineteenth century. Instead, shedding light on Sowerby's ideas will show the plurality and larger diversity of ideas that were around

In this chapter, I shall first explicate Sowerby's ideas about the role of black and white for the generation of colours in more detail. Once the importance of the contrast between black and white for the working of his method has become clear, I shall turn to the material variables that might influence the colours that are generated on a chromatometer. I will investigate to what extent the materials one could use to perform Sowerby's method influence the possibility of communicating about colours in a standardised way. This will provide us with insight into the reliability of Sowerby's method. Furthermore, comparing these material aspects with the extent to which Sowerby paid attention to them, and embedding these findings within larger debates about

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[123] Sowerby, *A New Elucidation of Colours*, p. 8.

[124] Tawrin Baker "Colour in Three Seventeenth-Century Scholastic Textbooks,“ In: *Colour Histories. Science, Art, and Technology in the 17th and 18th Centuries*, edited by Friedrich Steinle and Magdalena Bushart. Berlin, Boston, De Gruyter, 2015, p. 163; Friedrich Steinle, "Colour Knowledge in the Eighteenth Century. Practice, Systematisation, and Natural Philosophy." In: *Colour Histories. Science, Art, and Technology in the 17th and 18th Centuries*, edited by Friedrich Steinle and Magdalena Bushart. Berlin, Boston, De Gruyter, 2015, p. 44.

[125] Alan E. Shapiro, "Artists' colors and Newton's colors." *Isis* 85.4 (1994), p. 601.

the properties of these materials in the eighteenth and nineteenth centuries, shall enable me to make Sowerby's material assumptions explicit.

As has been explained in the introduction, three materials are needed to perform Sowerby's method: a sheet of white paper, pigments with which black patches of the right size and shape could be painted on this sheet, and a prism to show coloured bands at the border between the black and white to an observer who is looking through the glass. I shall investigate these in due order in this chapter.

Since Sowerby was very proud of his chromatometer method, he let the device be printed on "wove royal" paper. This expensive paper of an unusual large size expressed luxury. However, adoption of this type of paper also indicates that reproducibility of the chromatometer was no primary concern of Sowerby. If a contemporary of Sowerby wanted to use his method, and went searching for appropriate materials, what variability and what problems of standardisation could this person encounter? Sowerby elaborates very little on necessary materials in his *Elucidation* himself, or whether deviations from his original choices would have influenced the colours one would perceive on a self-made chromatometer. To investigate the influence of material variability on the uniformity of generated colours on chromatometers, I shall therefore use a method that historian of science Hasok Chang has coined as "extensions": variations in aspects of a historical method, mainly in its used materials, which are not mentioned in the original experimental descriptions, but that a curious reconstructor expects to be of influence on the final result. To limit the scope of my extensions reasonably, I shall focus on material variables regarding the types of papers and pigments that were available in Sowerby's time to create a chromatometer, and what effects variation of these materials would cause for the generated colours one would perceive on ones self-made chromatometer.

For this chapter I have deliberately chosen to present a (playful) exploration of a broad range of factors that might influence the colours perceived on a chromatometer, instead of a detailed and systematic investigation of all the possibilities related to a few (sub)variables. (It was for instance preferred to investigate many different types of paper fibres, and only investigate the influence of bleach on one of them, instead of testing the effects bleach might have had on more different paper fibres while limiting the total amount of fibres investigated.) An in depth study of these and other material factors, as well as more in-depth research into the influence of ageing processes on these materials, could be executed in future research.

Besides the chromatometer, made of white paper with pigments, one would need a prism to perform Sowerby's method. To shed light on his material assumptions, I shall analyse discussions about the properties of glass prisms during Sowerby's lifetime, and to what extent Sowerby interweaves them in his prescriptions for the selection of a prism. It will be shown that regarding the types of prisms available at that time, Sowerby's instruction leaves a lot of possibilities open. Using an "extensions"-approach, I therefore investigated an array of historical prisms in Museum Boerhaave, Teylers Museum, and the University Museum in Utrecht; prisms that all could have been used according to Sowerby's prescriptions. Would the variability in prisms that Sowerby tolerates have caused differences in the colours one could perceive on a chromatometer?

Black and white

In chapter one, I have set forth what colours Sowerby described to have observed, and which theoretical assumptions influenced what he perceived. But how did these colours come into existence in the first place? I shall now turn to the explanation of how these colours are generated according to Sowerby.

In one of his experiments, Sowerby asks the reader to look through a prism at a white sheet of paper. But when doing so, nothing remarkable will appear; one will just see the white paper. However, as soon as a streak of black is placed upon the paper, colours will become visible while looking through the prism:

> We should therefore look at the middle of a piece of white paper, or any white object, when if smooth, and free from spots or marks, we shall perceive no colour; but if a fine stroke of black be produced, pale tints or colours will be seen; but if more black is added, the colours will be more distinct in a certain proportion.[126]

[126] Sowerby, p. 18.

Colours, according to Sowerby, are created wherever contrast exists between black and white or light and shadow. It is important to note, that in Sowerby's view material and prismatic colours have exactly the same properties, and obey the same laws of nature. (We have already investigated this assumption more elaborately in chapter one.) Therefore, he treats observations created by light-shadow contrasts and material black-white contrasts as equal, and he interchangeably uses the terms "shade" and "blackness of pigments", and "light" and "whiteness of paper" throughout his book. This is for instance visible in the following quote: "any light with shade will produce prismatic tints; thus, as it were, reducing the production of tints to light and shade, or white and black."[127] Observing phenomena created in nature by the interplay between light and shadow, therefore, will generate colours similar to the ones one could perceive in an experiment with black pigment on a white paper:

> Rich lights, or whites, and full or more perfect darkness opposing each other, produce the more brilliant tints. The rich light of the sun dispelling the darkness of the morning, or passing away in the evening, produces more apparent colour than at noon when the whole atmosphere is illuminated; and a small candle in a large room, surrounded as it were by much darkness, gives as great brilliancy in the prism as the sun itself: and again, the prismatic rays collected from the sun require a quantity of shade to show them most brilliantly: — thus they were generally refracted into a dark room.[128]

How do these opposites create colours? As we read in chapter one, Sowerby had thoroughly studied Newton's *Opticks* and commented upon the experiments Newton described in it. Sowerby agreed with Newton that white light consists of coloured rays, and that these can be made visible by using a prism to separate different types of coloured rays. However, in Sowerby's view, only white light and a prism are insufficient to show these colours: shade or blackness is needed to "collect" these rays after their dispersion by a prism, so they become visible:

> Light, on an object when seen refracted by the prism, shows its colours; which however do not affect the general local tint of the object which seems to reflect it, but rather depend upon the darks or shadows; and broad flat masses of any coloured object do not appear changed excepting at the extremities, or where dark or shade seems to help to collect the coloured radii: thus it may be possible to make broad tints or narrow ones with such proportions of dark or shade as may be suited for many purposes of the utmost utility in the arts, manufactures, agriculture, &c.[129]

Because of its "collecting power", the larger the amount of black present on a white surface, the better the coloured radii will be collected, and therefore the intenser or more saturated the colours will appear: "It was just observed, that if we added more black the colours would be more distinct in a certain proportion; I may add, that they will be more vivid and apparently more perfect."[130] The lesser the amount of black, the fewer coloured radii will be collected from the light, and therefore the paler the tints will appear. Therefore, Sowerby proclaims that "I shall here denominate the black forms productors, as they appear to produce the colours."[131]

The deepest or most perfect black has the strongest collecting power, according to Sowerby. Although other colours can collect coloured radii as well, and thereby create coloured bands around them, these bands will never be as full and saturated as the ones created by pure black. To illustrate this, Sowerby describes the colours a yellow patch will create:

> Finding that artificial light and dark will, by means of the prism, in common daylight, give all the original tints, it was thought necessary to show that yellow […] artificially contrived or placed, produce[s] the three or more tints, and the tints so produced partake of the colour of the yellow, […] that produce[s] them [see figure 2.1a for an image of the colours created by yellow patches according to Sowerby]. The white space between the two yellows would produce a proportion of white, 1 a proportion of yellow, 2 a proportion of red, and 3 a proportion of blue. The yellow is pretty good, being produced by the prism

[127] Sowerby, p. 17.
[128] Sowerby, p. 17.
[129] Sowerby, p. 4.
[130] Sowerby, p. 18.
[131] Sowerby, p. 25.

from yellow. The red being produced by the yellow partakes of it, and forms an orange tint. The blue is pale and wants brilliancy, on account of the yellow being the palest of colours, therefore a bad substitute for black. The penumbra below the blue has a poor reddish tint, partaking of the yellow.[132]

Yellow is not capable to collect enough coloured radii to create a full red. Instead, it is only capable of creating an orange tint at the place where a red band should appear. The created blue band is not full and distinct either. On the contrary, some of the red rays that yellow could not collect at their right place, are instead drawn to the position underneath the blue. After describing this lack of colour-collecting strength of the yellow, Sowerby concludes: “Thus, black or dark in this case seems to have the power of producing these tints in a sort of neutral manner, as if it only relieved them in their utmost purity.”[133]

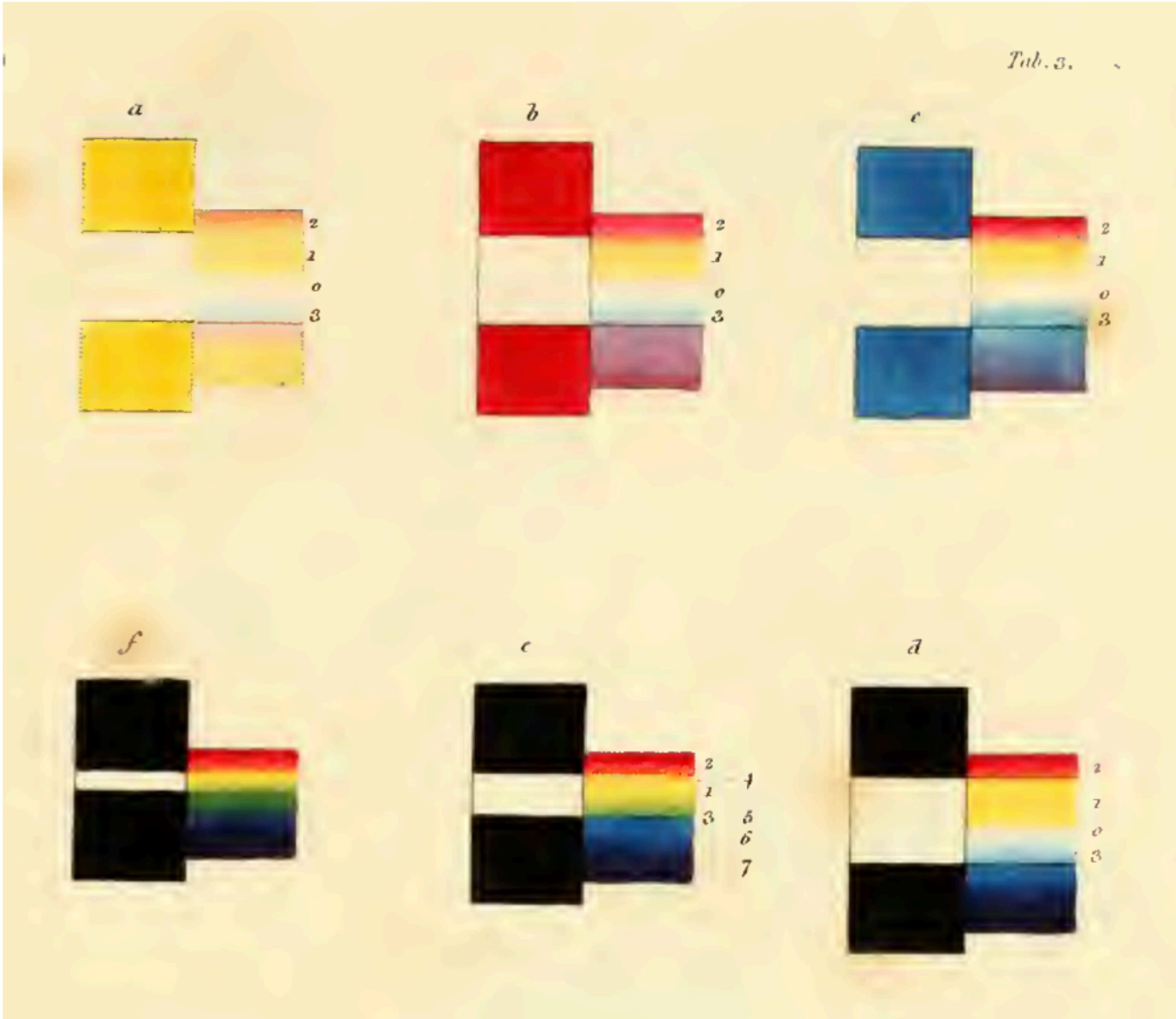

Figure 2.1: Depictions of the coloured fringes that would be generated when one looked through a prism at the respectively depicted yellow, red, blue, black-and-white patches. Sowerby depicted the fringes at the right of each patch in this figure, while in reality they would be visible on top of the patches. Sowerby, “Tab 3” In: *A New Elucidation of Colours*, 1809.

132 Sowerby, p. 20.
133 Sowerby, p. 20-21.

But the absence of black is not the only reason why tints of colours can become paler. We all know from observations in nature, Sowerby points out, that coloured materials will lose their colour when they are exposed to sunlight for too long: “Light is essential in colouring some things and bleaching others; […] Many chemical substances are changed by exposure to light; oils become whiter.”[134] Light may consist of coloured rays, and be able to create the perception of colour for substances it shines on, at the same time it works as a bleaching agent. This is also visible in the language with which we describe colours: “light yellow” for instance describes that a full yellow has been bleached by light, and therefore appears paler to the human eye. “Thus light yellow is yellow distinct, mixed with light or white in such a proportion that it has not another tint, as a little more white would somewhat obliterate or disguise it.”[135] We see here how Sowerby weaves words for light and material colours in a figurative way - as if it were that coloured materials and light rays could be mixed in an analogous way with light-or-white in a proportion which could be more or less, thus adapted to effectuate a meant effect, to be lighter or paler.

Adding white to a pigment mixture, or creating a larger amount of white upon a surface, will have the same effect as adding light: it makes colours appear paler: “a narrow line of black [on white] gives the appearance of three tints chiefly, and those pale, as if it were diluted with white.”[136] In sum, the larger the black patch is, the better coloured rays that come out of a prism can be collected, and the deeper the colour will be. While the larger the white or light area is compared to the black, the more the bleaching effect will be at play, making the colours paler. Sowerby regards this bleaching process to work not only in the long term, as can be observed in material colours, but also instantaneously, as can be seen when one looks through a prism at a white-black interface.

Sowerby puts these theoretical assumptions into practice for the creation of his chromatometer. Since blackness enables the collection of the coloured radii on and in contact with it, coloured bands will appear everywhere where black patches are painted upon white paper. Sowerby’s chromatometer starts with a rectangular patch of black at the upper left corner of the paper (see the red squared part in figure 2.2). Sowerby chose the dimensions of this rectangle, which he calls an “index," to be such that around this rectangle the most brilliant and saturated colours would appear. According to Sowerby’s own trials, the collecting power of the black is not limitless. This means, that with more and more black added, there is a maximum on the brilliance and saturation of the colours. A higher patch of black is therefore unnecessary, since this will not generate more perfect colours:

> This wedge, at the beginning including the index, contains five divisions which is equal to a much broader black space, for perfect red is given where it is four parts, and no greater width will give so perfect a red.[137]

This initial black rectangle can be used as an “index” to calibrate if a prism is held at the right distance and angle, since everyone who looked through a prism at this rectangle should see the most perfect colours appear at this position.[138] (For which Sowerby apparently tacitly assumes that everyone using a chromatometer not only agrees what the most perfect colours are, but also that the user possesses knowledge of what these colours look like; since he does not give a further explanation.)

Starting with this rectangle at the left, attached to it a black wedge-shape appears, with the height of the black line gradually decreasing. The complete wedge is cut into pieces below each other and decreases further along each new line.The black wedges below the first one are in fact each of them the linear continuation of the one just above them. In measurements they all start at their left side with a height similar to the smallest height at the right side of the wedge above. In this way, the colour collecting power of the black is reduced further and further when one moves ones eye - looking through the prism - to the right along the black lines, and from the upper one to the lowest one; while at the same time the bleaching effect of the white paper surrounding them will increase. In consequence, the coloured bands one can perceive through a prism will gradually lose their brilliancy, strength, and state of perfection. The lowest wedge ends in a point. Thereafter the contrast is gone, and no colours will be visible anymore.

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[134] Sowerby, p. 4.
[135] Sowerby, p. 35.
[136] Sowerby, p. 22.
[137] Sowerby, p. 26.
[138] Sowerby, p. 26.

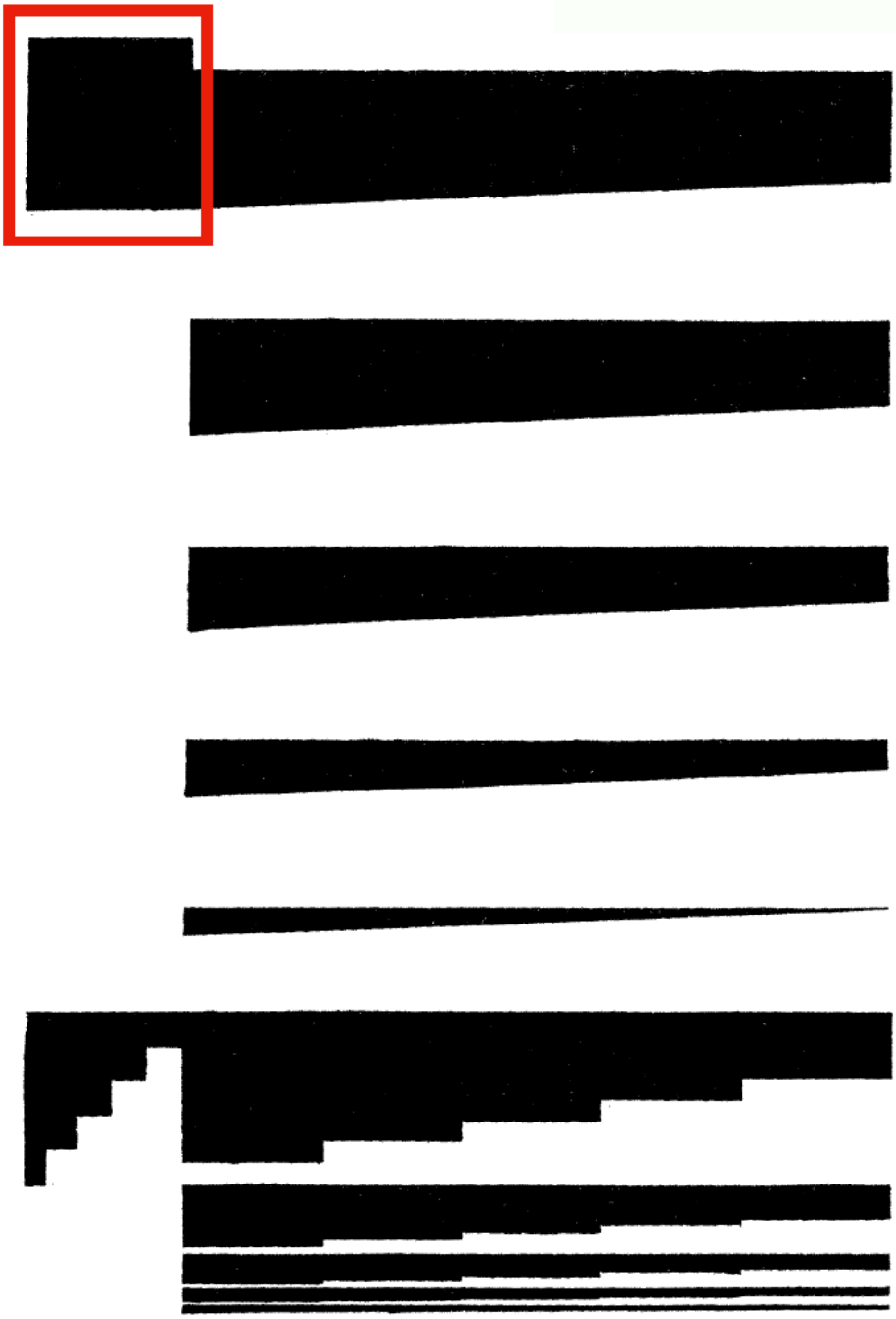

Figure 2.2: The chromatometer, with a red square added to indicate the index. Sowerby, “Tab 7” In: *A New Elucidation of Colours*, 1809.

As we could read in the introduction, around these wedges only bands of the primary colours would be created, not all colours observable in nature. As we have read in chapter one, Sowerby regarded blue, red and yellow to be the primary colours, from which all other colours could be derived by mixing them. And one of the means by which one could mix light’s prismatic colours, is to let them overlap. In the chromatometer, when one reduces the white space between two black patches, the primary colours visible around them will be pushed over each other. Red overlapping yellow will create orange, and yellow overlapping blue will form green:

> It appears that the primaries chiefly depend on the edges of the white and black of a certain proportion in contact, and that orange and green depend on the narrowness of the white between two black edges: thus a broad light upon black effuses yellow, red and blue, the red and blue always bordering more or less on the black back ground, and the yellow appearing upon some part of the space of light or white, whatever light it is, even the shining or gloss light on any black or dark coloured surface; and should the light be narrow, the blue on one side and the red on the other mix with the yellow, independent of the motion of the prism; and that the light being still narrower, the yellow is lost in green formed by its mixing with the blue.[139]

Notice again in the quote above that Sowerby uses "white" and "light" interchangeably. He himself indicates that the nature of what light is remains somewhat elusive to him, but thereafter he prefers the term "light" to indicate that if the white surface between two black patches is reduced, the yellow band starts to overlap with the blue band on the one side and the red band on the other side, creating the mixing colours green and orange. We can see this idea effectuated in the staircase shaped part of the chromatometer at the bottom of the paper: here, lines are placed so closely together, that by means of overlap the secondary colours orange and green appear. However, purple, that is created by mixing red and blue, cannot be created by reducing the white space between two black patches. Here a different aspect of the chromatometer is at work, of the approaching borders of the black. Red and blue colours border the black patch creating them. On the white paper a yellow band will always intercept them. However, when the black lines in the wedge shaped part become smaller, not only the tints become paler, but the red band and the blue band will start to approach each other as well. At the smallest end of the wedge red and blue will gradually overlap and the black between them will become invisible. And "when the red reaches the blue side, it becomes purple, soon after which they may be lost in the narrowness of the line."[140] Sowerby concludes: "Thus a single light space may be contrived to show with the prism white, yellow, red and blue; and by mixture, orange, green and purple. So that we have primaries and binary compounds."[141] And in addition, the interplay between the collecting power of the black, and the bleaching power of the white, will enable one to create all possible tints of these colours.

But for any constructed chromatometer, there is a danger lurking around the corner: light, according to Sowerby, does not only have a desired immediate bleaching effect on coloured bands seen through a prism, by which differentiation in saturation can be produced. Light can also degrade the chromatometer material, by bleaching its black - pigment based - wedges. To avoid unnecessary exposure to the sun, Sowerby recommended to hang the chromatometer at a shaded place. In this way, it will be stored more durably.[142]

However, before one could hang a chromatometer on one's wall, one should first obtain one. We shall now turn to some manners in which one could do so, with their accompanying material variables.

Papers

The first material vital for the making of Sowerby's chromatometer was paper, since this provided the physical support of the chromatometer as well as the whiteness needed to generate the colours. And since Sowerby regarded the contrast between black and white as essential for his method, the whiteness of the paper used might have been a factor of influence, to enhance or maximise this contrast. However, when it comes to the types of paper a nineteenth-century reader of Sowerby could have employed, the options are near to endless. In the ages up to the nineteenth century, the shortage of linen and cotton - the common materials that paper was made of during the period - became more and more pressing. Already in 1666, the English Parliament had decreed that only wool should be used in burying the dead, to save linen and cotton rags for the production of paper. From that year onwards, "it was contrary to good citizenship to make use of linen or cotton clothing for burial. All garments used for this purpose had to be made of wool, a

139 Sowerby, p. 19.
140 Sowerby, p. 19-20.
141 Sowerby, p. 20.
142 Sowerby, p. 27-28.

material unsuited for papermaking."[143] At the turn of the nineteenth century, shortages of linen and cotton had become so urgent that there was an outburst of experiments with different materials that might be suited for papermaking. Although most proposed materials, like asbestos and seaweed, never reached a commercial scale of production, in 1800 the London papermaker Matthias Koops (1776 - 1812) was the first to produce paper made from straw and wood, on a commercial scale.[144] Furthermore, during this period papers from the east, made from different materials - but more importantly with different optical properties due to alternative production methods - became accessible to an increasing group of customers.[145] As to the whiteness as a quality of paper, it was discovered that papers appeared whiter when the wood-fibres they were made of were frozen before they were taken into production.[146] Therefore, paper made during winter had a whiter appearance, and was regarded to be of better quality compared to paper made during summer.[147] And while Karl Wilhelm Scheele's invention of bleach based on chlorine to make paper whiter from 1774 was officially patented in England during Sowerby's time, already in 1792 a booklet with the title *Memorial relative to the Invention of a New Method of Bleaching, Showing the Absurdity of Any Pretensions to an Exclusive Privilege for Using It in the Paper Manufacture* had been published, and the patent is likely to have been ignored widely.[148]

Luckily, Sowerby's contemporaries would not have needed to bother about this variability in the available types of paper, and whether the differences in colours between them would have influenced the colours one would generate with his chromatometer method, since Sowerby advertises at the end of the *Elucidation* that one can buy a chromatometer for 2s. 6d. at his local printer in London: Richard Taylor and Co. of Shoe Lane. All these chromatometers would have been made by the same manufacturer, and therefore would likely all have been printed on the same type of paper: the expensive "wove royal" paper.

It is interesting to note that Sowerby used a special type of paper to print his chromatometers on, since this indicates that he paid special attention to the quality of the medium on which his patches arrangement could be painted. "Royal" refers to the size of the used sheets, which is larger than the standard format, and therefore was used to express luxury. "Wove" refers to paper that was made by using a special moulding technique, that was introduced in 1754 by James Whatman and William Baskerville. A problem with regular paper is that it contains chain lines - impressions of the mold that was used to scoop the paper. If a painter makes a mistake and tries to remove pigment from his or her sheet, pigment can hardly be erased out of these cavities. On top of that, paper is slightly thinner at the positions of these impressions, which weakens the strength of the sheet. "Wove" paper is scooped in such a way that no chainlines are impressed into the pulp. These papers therefore have an extra smooth surface, which makes it stronger and attractive for painters and other people working with – the optical effects of - pigments.[149]

However, with respect to Sowerby's contemporaries interested in his chromatometer method, to obtain his *Elucidation* with a chromatometer was a matter of patience. We recall how, in chapter one, I narrated about Goethe's attempt to obtain one for himself in Weimar. It took five months before he had one in his possession, even though Goethe had an elaborate network with multiple contacts in London who were able to search for him. Sowerby claimed that his method would enable universal communication about colours between savants all over the globe. But it is known that the transfer of items with correspondents that lived at a greater distance from London

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143 Dard Hunter, *Papermaking: the history and technique of an ancient craft*. Courier Corporation, 1978, p. 311.

144 Hunter, p. 332; 375.

145 Hunter, p. 188; 191-192; Ad Stijnman, *Engraving and Etching, 1400-2000: A History of the Development of Manual Intaglio Printmaking Processes.* PhD dissertation, Archetype Publications, 2012, p. 236.

146 Armin Renker, *Das Buch Vom Papier: Von Armin Renker.* Insel-Verlag, 1951, p. 142; Stijnman, p. 236.

147 Johann Georg Krünitz, *Oekonomische encyklopädie*. Vol. 11. J. Pauli, 1777, p. 588.

148 Hunter, p. 312; 316, 318.

149 "J Whatman: the master of western papermaking." *Vintagepaper,* Apr 07, 2019. https://vintagepaper.co/en-nl/blogs/news/drying-paper-at-whatmans-springfield-mill Accessed 29-01-2024.

frequently took even longer, up to four years.[150] Therefore, it seems improbable that savants working at the other side of the globe would attempt to obtain a chromatometer from Sowerby's local printer instead of creating one themselves. Also it would be uncertain if later developments with regard to press and paper would influence the guaranteed availability of Sowerby's chosen "wove royal" paper. Furthermore, it is probable that part of the technical details of his chromatometer like pigment mixture would get lost to the interested researcher, for instance when his printer somehow ended the production of the chromatometer. The claim for universality of Sowerby for his method thus deserves closer attention on this material aspect: how a quality of the used paper would influence the results, i.e. colours that are produced using a prism and the chromatometer.

For my investigations if and how papery media could influence the colour effects on a chromatometer, I decided to include a variety of paper sheets made from historical materials that were used for paper at other parts of the globe, such as coconut shell, hemp and abaca (a fiber obtained from banana plants). The Albert Sperisen Library in California possesses a large collection of these types of papers, that I was allowed to investigate for this thesis. For reasons of conservation and availability it was not possible to turn historical papers into chromatometers for my investigation. Instead, I focussed on the aspect of paper that Sowerby regarded to be most important: its whiteness. Investigation of the effect of translucency, roughness, irregularities and other paper materiality related factors might be included in future research.

The procedure I followed was as follows: first, photographs of the handmade papers in the Albert Sperisen Library were made, that included a Pantone colour chart, so I could thereafter adjust the colours of the photographs made by the camera to the same colours as the real papers had. Thereafter, I created chromatometers of the exact same dimensions and with the exact same ink on papers of these colours (see figure 2.3). These chromatometers were all photographed under the same conditions: with a Canon EOS 350D camera (ISO 1600; shutter speed 1/25; f stop 8,0); at exactly the same location; with the exact same lighting conditions (lit by two Philips Tornado T2 12W light bulbs); through the same triangular crown glass prism that was held in the same position with the same orientation for each photograph. These photographs were colour standardised with a Calibrite Colorchecker Passport Photo 2, using *ColorChecker Camera Calibration* and *RawTherapee* software.[151] From these photographed chromatometers, four samples of 5x5 mm were taken in similar locations in each photo: one sample of the paper, one of the red band visible at line 1 at 3.0 cm, one of the dark blue band visible at line 1 at 15,2 cm, and one of the light blue band visible at line 2 at 12,3 cm (see figure 2.4). These squares are combined in the 4x4 matrices of figure 2.5. In this way the reader can easily compare the possible differences between the coloured paper sheets and perceive the colours of the prism-generated fringes projected on each sheet.

One can thus perceive the extent to which differences between the darkness of the investigated paper samples effect the colours of the bands. I observed that the samples of the coloured bands generated on these different paper samples seem to follow a pattern: the fringes of colour on a dark paper appear darker to the eye compared to the fringes on the brighter papers. Subsequently, for all of these samples, the brightness values (L*) were determined with a digital colour measurer. L* values range from 0, which indicates total absence of light; deep black, to 100, maximum brightness or white. Furthermore, the redness and blueness values were determined, for which 0 indicates a total absence of the colour in the sample, and 255 a maximally saturated sample with this colour.

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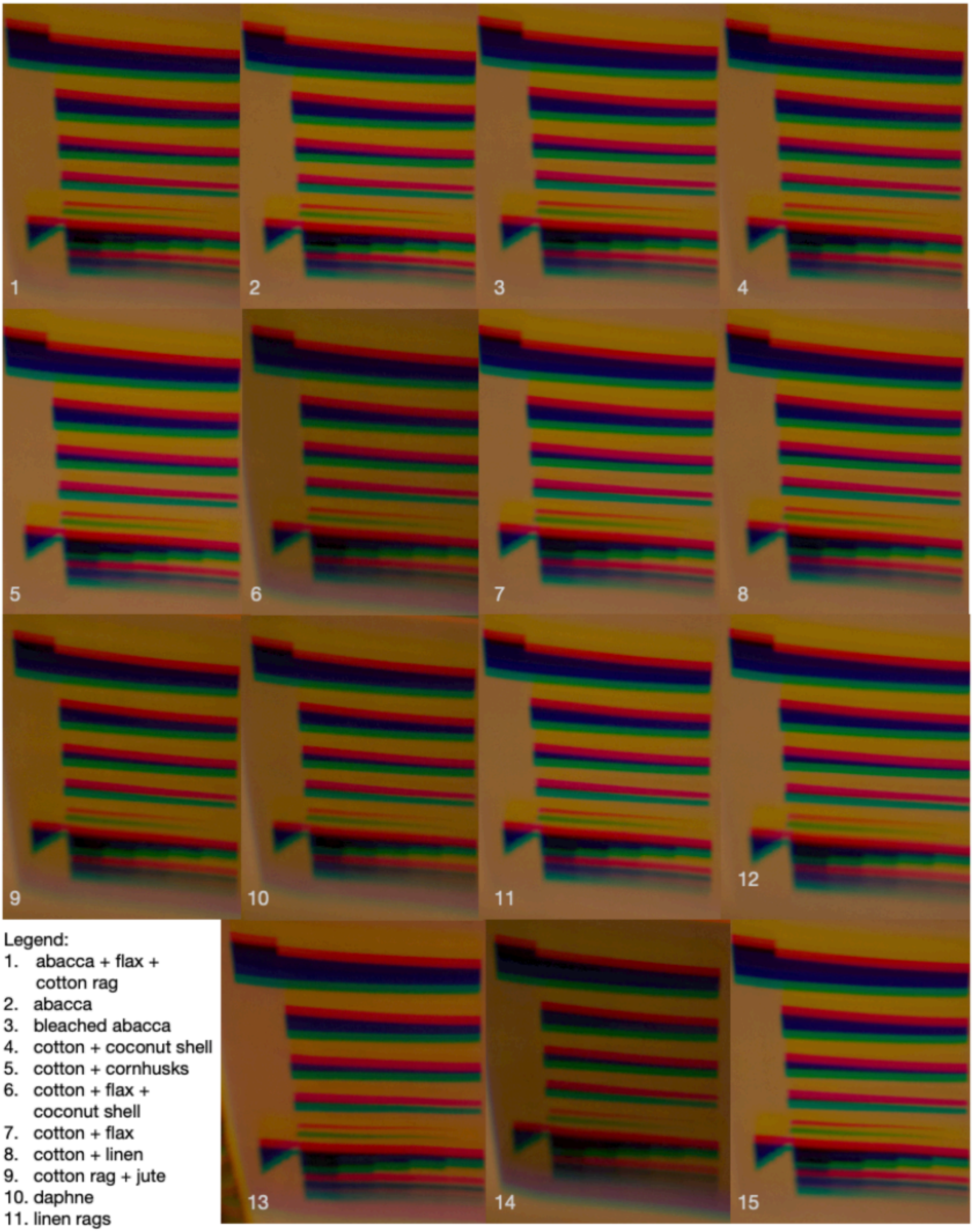
150 Paul Henderson, "James Sowerby: meteorites and his meteoritic sword made for the Emperor of Russia, Alexander I, in 1814." *Notes and Records of the Royal Society* 67.4 (2013), p. 393.

151 The pigments and papers have been analysed based on photographs made with a Canon EOS 350D camera. To improve the reliability of the visible colours, all photographs were colour standardised with a Calibrite Colour Checker Passport Photo 2, and processed with RawTherapee software. However, it would have been even more reliable if the colours had been captured with a hyper-spectral camera, or with an spectroradiometer. These techniques were not available for this thesis, but might be preferred in similar future research.



Legend:
1. abacca + flax + cotton rag
2. abacca
3. bleached abacca
4. cotton + coconut shell
5. cotton + cornhusks
6. cotton + flax + coconut shell
7. cotton + flax
8. cotton + linen
9. cotton rag + jute
10. daphne
11. linen rags
12. printing paper (modern reference)
13. rice + straw + bark
14. hemp
15. straw + abacca

Figure 2.3: Photographs of the chromatometers created on backgrounds with colours identical to the colours of the historical paper samples from the Albert Sperisen Library viewed through a crown glass prism. (Photographs by the author.)

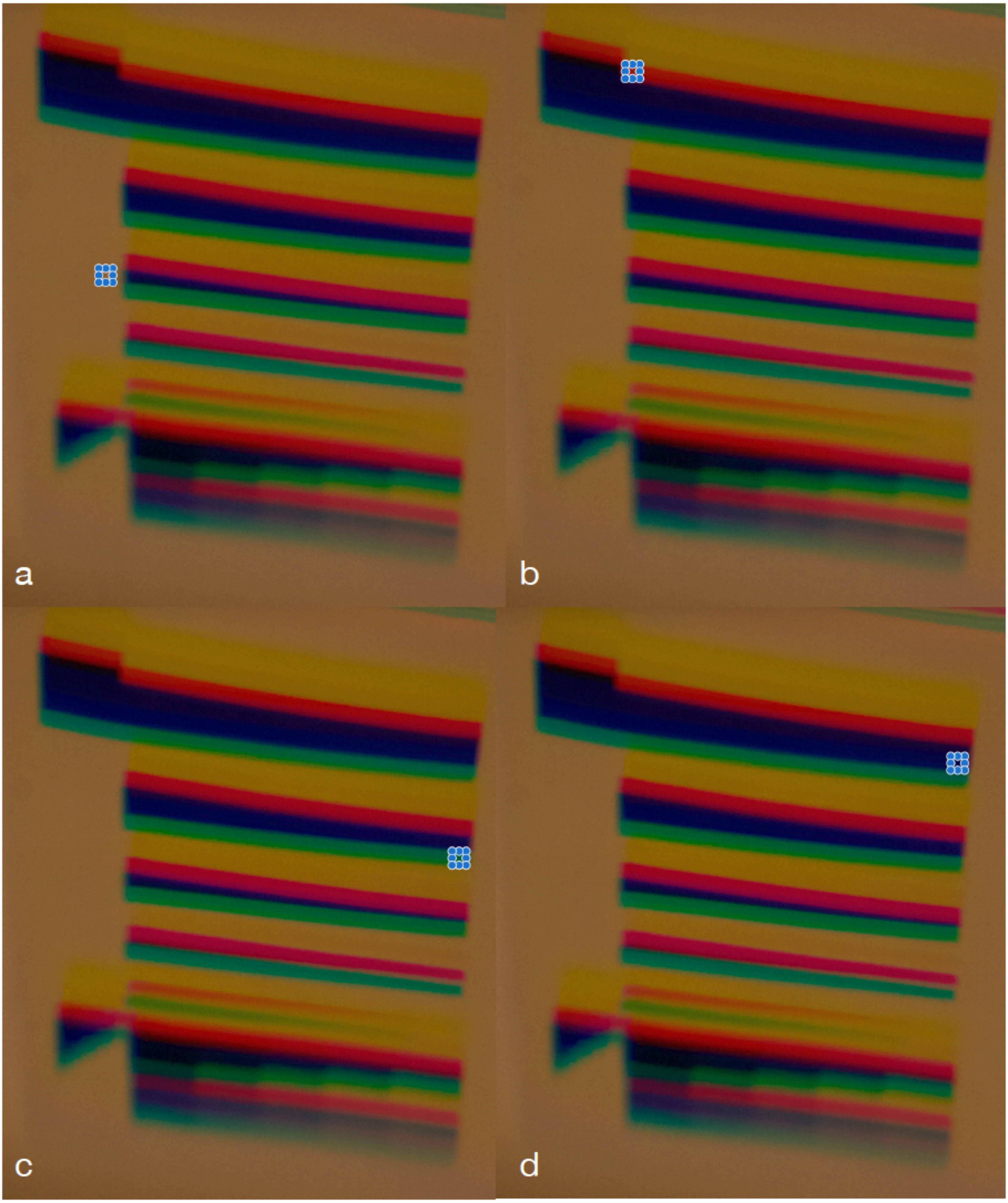


Figure 2.4: Photographs of the chromatometer with a linen paper-coloured background, on which I indicated the locations were the samples of the colours were taken. For each of the papers (see figure 2.3), the sample was taken from this exact spot. All paper colour samples were obtained at the location marked in a, and the samples of the red, light blue and dark blue fringes were obtained at the locations indicated with b, c, and d respectively. (Photos by the author.)

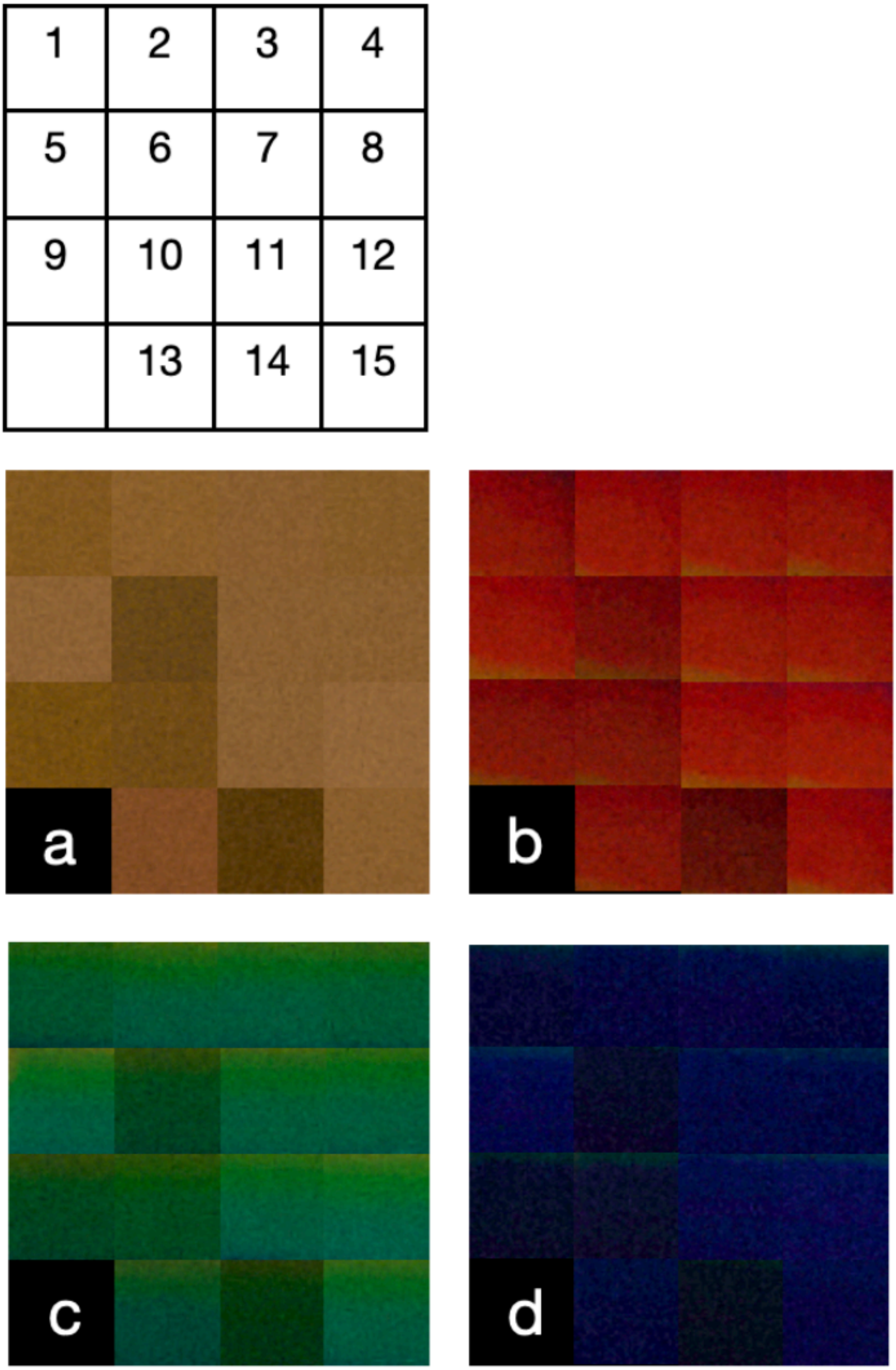


Figure 2.5: All paper samples as numbered in the legend of figure 2.3 rearranged as the diagram at the upper left shows. The 4x4 colour matrices show these chromatometer samples to enable quick comparison of the colours of the similar fringes. Matrixes respectively of the paper colours (a), red (b), light blue (c) and dark blue (d) fringes. (Collages by the author.)

It turns out that there is a strong correlation between the redness and blueness of the paper and the perceived colour of the fringes: the redder the tonality of the used paper, the redder the red bands will appear (r = 0,958), and the bluer the tonality of the used paper, the bluer the two blue bands will appear (r = 0,992 for dark blue, and r = 0,922 for light blue). A similar correlation can be found between the brightness of the paper and the brightness of the red and light blue coloured samples (r = 0,968 for the red band, and r = 0,917 for the light blue band). This indicates that how darker the paper is on which a chromatometer is made, the darker the colours created on that chromatometer will appear. However, the relation is not one on one. If the L* of the paper decreases with 1 point, the red and light blue fringes will only darken 0,6 and 0,8 respectively (rc = 0,651 for red and 0,846 for light blue).The dark blue band is so dark by itself, that the darkening of the paper does not seem to influence its colour (rc = 0,057).

Does the finding that on darker paper, the coloured red and light blue fringes appear darker, also indicate that these differences would be perceivable? I observed that differences in darkness of the sample patches are not only visible in the square with paper samples, but also in the squares with the different samples taken from the red and light blue coloured fringes. A pending question is, how dark the paper should be to observe significantly other tints of colours at the same position on the chromatometer, and which amount of darkness would therefore compromise Sowerby's method. The International Commission on Illumination / Commission Internationale de L'Eclairage (C.I.E.) in 1976 proposed a formula with which the colour difference between patches with different colours or tints of the same colour could be calculated, resulting in the so called ΔE value. This formula has meanwhile been improved multiple times, and currently a cluster of formulae, together named the CIEDE2000 is in use. This elaborate set of formulae allows one to calculate ΔE values based on measured L*a*b* values. L*, an indication of brightness, has already been described above, a* gives an indication of the greenness or redness of a colour, and b* gives an indication of the blueness or yellowness of a colour. Both values run on a scale from -127 to +127. The CIEDE2000 formula furthermore corrects for differences in hue and chroma between colour patches, and its validity is substantiated with data from multiple participant studies.[152] The extent to which one can perceive differences between colour samples differs based on viewing conditions, and from person to person. For instance the distance between the patches; the background colour; lighting conditions; observation time; training and experience of the observer will influence the extent to which one would perceive differences. But as a rule of thumb, ΔE values of 2.25 and lower are not perceivable to the average observer; values between 2.26 and 5.00 will be perceivable with difficulty, and values above 5.00 will be perceivable at a glance. Values of 100 indicate the maximum difference between two colour swatches.[153]

As has been described above, in Sowerby's time many types of paper, made from many different materials were available. However, cotton and linen remained the main materials paper was made from.[154] For that reason, in my analysis I shall use the paper sample made from a combination of cotton and linen as the standard, and focus on reporting if someone using a chromatometer created on a paper made from another material fiber from the selection would have perceived a noticeable difference in the colours generated on this paper. For five of the papers, one should not perceive any noticeable difference (ΔE values below 2.16). For another three papers, one should be able to perceive a noticeable difference if one paid attention (ΔE values ranging between 3,07 en 3,53). For the last five papers, differences would be clearly perceivable. I shall detail on these findings below.

Between hemp and the cotton-linen rags, the darkest and the whitest paper investigated here, the difference in tint would be clearly perceivable for all investigated coloured fringes (ΔE red = 10,88; ΔE light blue = 12,06; dark blue = 11,79). And between jute and the cotton-linen rags, differences should also be perceivable for the blue fringes (ΔE light blue = 8,15; dark blue = 7,57), since the blue bands would have a lot deeper blue tinge when seen on a linen and cotton mixture,

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152 Ming Ronnier Luo, Guihua Cui, and Bryan Rigg. "The development of the CIE 2000 colour-difference formula: CIEDE2000." *Color Research & Application: Endorsed by Inter-Society Color Council, The Colour Group (Great Britain), Canadian Society for Color, Color Science Association of Japan, Dutch Society for the Study of Color, The Swedish Colour Centre Foundation, Colour Society of Australia, Centre Français de la Couleur* 26.5 (2001): 340-350.

153 Phil Green, "Colorimetry and colour difference." In: *Fundamentals and Applications of Colour Engineering*, Wiley, 2023, p. 27-52. https://doi.org/10.1002/9781119827214.ch2

154 Hunter, p. 154.

compared to a jute and cotton mixture (Blue values of 42 compared to 19 for light blue, and 31 compared to 51 for dark blue respectively). For the red band, however, differences should be perceivable with more difficulty (ΔE 2,54). Jute and hemp might not seem to be logical choices for paper, but they have been common source materials for papermaking in India and Russia throughout the centuries.[155]

It has been noted that Chinese paper could look very gray after production, since tree-bark was used as its main constituent, and some Japanese papers are also renowned for their strength and durability because tree-bark is incorporated in its fibrous mixture.[156] Between the cotton-linen paper and the paper containing bark, one should be able to perceive a noticeable difference at a glance when it comes to the colour of the paper itself (ΔE 5,59), and also the light blue band would be of a distinctive colour when viewed through a prism (ΔE 8,74). However, the difference in tint for the red fringes should be less easily perceivable (ΔE 3,56), and should not be perceivable for the dark blue band (ΔE 2.25). This high ΔE value for light blue is caused by a combination of a lower brightness (L* 23,86 compared to 33,19 of linen), and the less green present in the band (Green value 52 compared to 74). Therefore, the darkness of the paper, as well as the colour of the less greenish tree-bark influence the perceived colour of the light blue fringe.

"In Nepal the *Daphne cannabina* is the bark used in making the large sheets of paper."[157] And daphne also should create noticeably differently coloured blue fringes on a chromatometer compared to one made on linen and cotton (ΔE light blue = 7,84; dark blue = 6,68). Here also, the difference for the red bands should be perceivable, but with more difficulty (ΔE 3,47). The daphne paper turns out to be less bluish compared to linen and cotton rags (B value 19 compared to 37), and therefore the blue bands appear less blue as well (18 compared to 42 for light blue, and 35 compared to 51 for dark blue respectively).

The last paper that shows a clear difference in the colour of the perceived fringes is the paper containing coconut shell and flax, besides cotton. This fibrous mixture should create clearly noticeable differences for all analysed coloured bands (ΔE red = 5,44; light blue = 8,39; dark blue = 5,24). However, I have not found any literature indicating that coconut shell in combination with flax was frequently used as a constituent for paper in history. It is interesting however, that I expected the perceivable differences of the bands on this dark paper to be caused by the presence of the coconut shell, however, pure coconut shell turns out not to give a perceivable difference compared to cotton-linen paper (ΔE paper = 2,13; red = 0,76; ΔE light blue = 1,17; dark blue = 1,38), nor does flax in isolation (ΔE paper = 2,09; red = 1,73; light blue = 0,40; dark blue = 1,03). Of course, the colour of a fibre used for paper will not have been exactly the same at different times, locations, or even between different batches, which might cause huge differences in the colour of the produced paper. This could further be analysed in future research. Furthermore, the differences in colour might not solely be dependent on the type of material used, but could also be caused by the production process of the paper.

As has been described above, bleach was becoming available to a growing extent in Sowerby's time to make paper whiter. Among the historical paper samples I could investigate for my thesis were bleached as well as unbleached abaca. The coloured bands generated on chromatometers from these materials showed no perceivable difference when compared to the linen-cotton paper (ΔE values ranging between 0,93 and 2,22). Nor did they show perceivable differences when compared to each other (ΔE paper = 1,54; red = 1,14; light blue = 1,41; dark blue = 1,05). Therefore, bleach does not seem to have a perceptible effect on the base colour and generated coloured bands for this specific paper fibre. In future research, it might be investigated if this would be different when other types of paper fibres are bleached and subsequently are used for chromatometers.

In North-America, paper made of corn husks was patented in 1802. Since corn husks are lighter than linen or cotton rags, transporting them was cheaper, making it economically profitable to substitute linen and/or cotton with corn husks as fiber material.[158] Contrary to the pattern that seemed to emerge above, that the blue fringes are effected more compared to the red fringes, if corn husks are used instead of linen-cotton, the blue fringes should not be noticeably effected (ΔE light blue = 0,55; dark blue = 0,99), while one should be able to perceive a slightly different colour of the red fringes (ΔE 2,78).

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[155] Hunter, p. 151; 223.
[156] Hunter, p, 204.
[157] Hunter, p. 233.
[158] Hunter, p. 397.

As was described above, Mattias Koops had initiated a paper mill in England that produced paper made from straw in 1800, just a few years before Sowerby published his *Elucidation*.[159] The substitution of straw paper for linen-cotton paper to make a chromatometer with, does neither seem to create perceivable differences in the generated colours (ΔE paper = 2,15; red = 1,36; light blue = 1,68; dark blue = 2,38).

To fully grasp how variations in paper materials could influence the perceived colours on a chromatometer, a much more extensive studie could be executed, with many more variables regarding production procedures, used chemicals during the process, the exact parts of plants used to make fibers from, and source materials from different times and localities, to name a few. However, based on this limited exploratory investigation, some preliminary conclusions can be drawn: the darkness and colour of the used paper influences the brightness and colour of the coloured fringes visible on the paper. Although there seems to be no noticeable effect for many paper fibres that were used in Sowerby's time, such as straw, corn husks, and abaca, for dark paper fibres such as jute, hemp and tree-bark, this could significantly influence the perceived colours on a chromatometer. These materials were used by Sowerby's contemporaries to make papers with, but would not be recommendable to make a chromatometer. When it comes to the paper support one would paint ones chromatometer on, it is important to follow Sowerby's recommendation and use a very white paper.

Pigments

The second extension that I will examine is the influence of different types and origins of black pigment on the optical effects of Sowerby's method. It might come as a surprise that Sowerby proposed to use pigments as an integral part of his chromatometer, since he developed a method to generate colours out of light instead of using pigments – precisely because he regarded the latter to be unreliable. However, to create a chromatometer one only needed to create black patches, and black pigments are known to be amongst the stablest existing pigments, especially the ones Sowerby recommended: lamp black and Frankfurter black.[160]

Still, Sowerby indicates that there is another problem connected to the use of these two pigments. Namely, lamp black has a bluish undertone, and Frankfurter black a brownish undertone. This problem can be overcome according to Sowerby, and he explains how:

> As perfect black is rather a desideratum in printing, I might advise transparent red or blue, which may be added to lamp or Franckfort black, to take from their dull opacity,— the red to the lamp black, commonly called blue black; and the blue to the other when too brown.[161]

The bluish undertone of lamp black can be counterbalanced by the addition of red pigment, and the brownish undertone of Frankfurter black by mixing it with a blue pigment. This means that somebody reconstructing Sowerby's chromatometer would also need stable red and blue pigments to achieve the right colour of black. Sowerby advises his readers in this regard as well, recommending them to use the red and blue he himself has found to be the most stable: carmine and Prussian blue.[162]

What Sowerby does not confer to his readers, is what proportions of these pigments should be mixed to obtain the "perfect" black colour he meant to be created. Instead, he advises to leave the mixing to a printer, since "a discreet printer will know by a trifling hint what to do."[163] It might be reasonable of Sowerby to refrain from prescribing ratio's to counterbalance the brownish or bluish undertone perceived in the black pigments, since the undertone one would encounter when using one of these blacks could vary from batch to batch (see figure 2.6).

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[159] Hunter, p. 333-340.

[160] Ad Stijnman, "The Colours of Black Printing Inks for Blockbooks" In: Wagner, Bettina, *Blockbücher des 15. Jahrhunderts: Eine Experimentierphase im frühen Buchdruck. Beiträge der Fachtagung in der Bayerischen Staatsbibliothek München am 16. und 17. Februar 2012.* Harrassowitz, 2013, p. 67.

[161] Sowerby, p. 40.

[162] Sowerby, p. 37-39.

[163] Sowerby, p. 40.

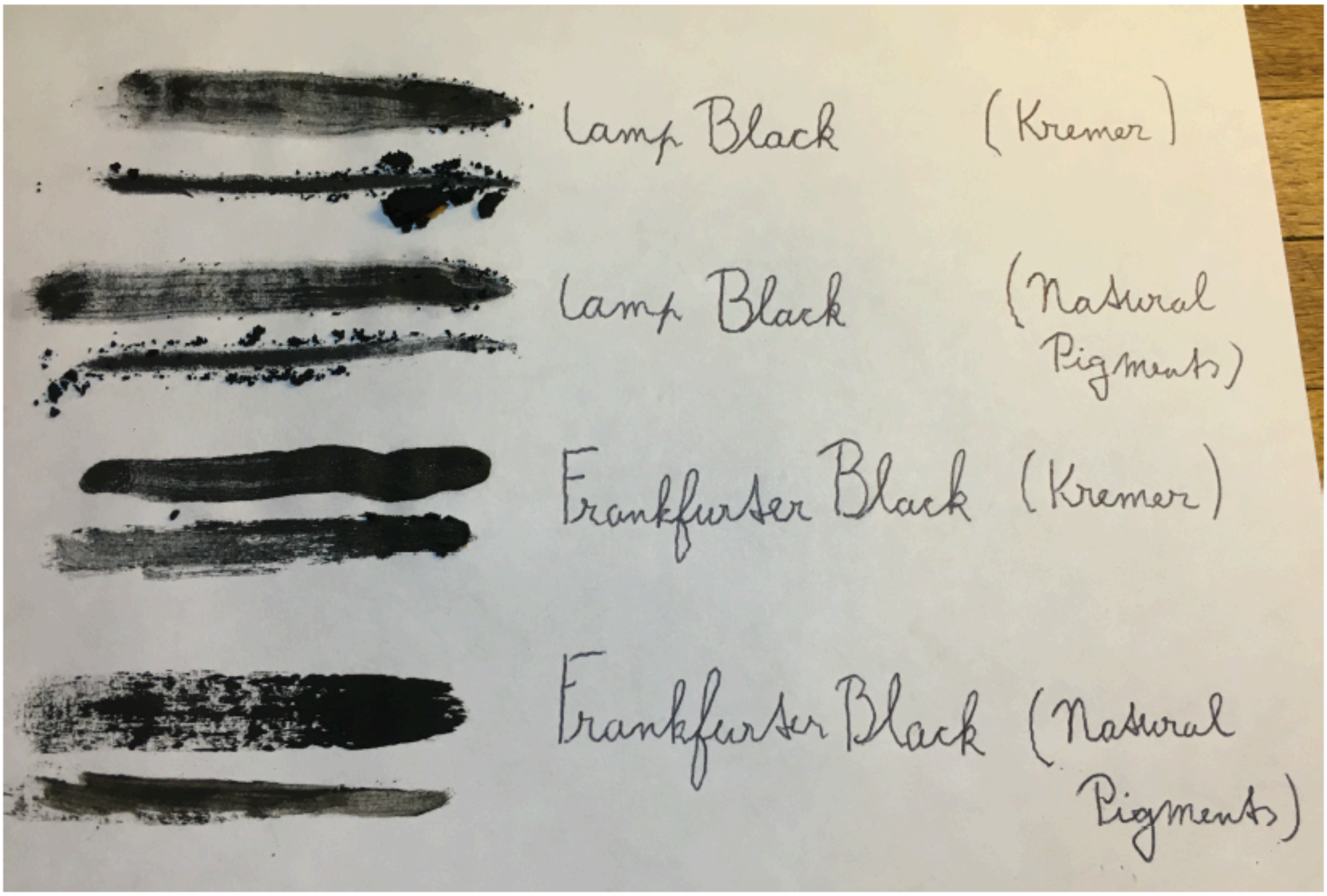

Figure 2.6: Black pigments (top-down left), with pigment names (middle) and manufacturer (right). The upper line for each pigment shows a paint-out of a water-colour mixture (containing the pigment, gum arabic and water), in line with the materials Sowerby used for his pictures in *A New Elucidation*.). The lower line shows a streak of the dry pigment. (Photo by the author.)

To create a “perfect” black the variability of the composing elements should be taken into account. In the first place, both lamp and Frankfurter black are based on plant materials that turn black during a combustion process. Lamp black could be made by burning a wide variety of oils, that based on their slightly different chemical composition would create different shades of bluish black. Frankfurter black was obtained by burning waste products of the wine making process, which could be either the grape vines, or the wine lees (debris mainly containing the grape seeds left after juicing the grapes).[164] Both sources of Frankfurter black would create a pigment with a different undertone when burned to ashes.[165] Furthermore, if wine lees of red grapes were burned, the obtained black colour would be more reddish compared to the ashes of burned white grape lees.[166]

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164 Ad Stijnman, “Frankfurt Black: 'Tryginon appelantes, faex vini arefacta et cocta in fornace’.” In: *Trade in Artists' Materials: Markets and Commerce in Europe to 1700,* edited by Jo Kirby et al., Archetype Publications, 2010, p. 415-417; Birgit Reissland, "A Practical Guide to the Production of Black Pigments and the Preparation of Black Watercolours, 1350–1700." In: *Burgundian Black: Reworking Early Modern Colour Technologies*, edited by Jenny Boulboullé and Sven Dupré. Santa Barbara, EMC Imprint, 2022, par. 2.5.
165 Stijnman, “The Colours of Black Printing Inks for Blockbooks,” p, 62.
166 Stijnman, “Frankfurt Black: 'Tryginon appelantes, faex vini arefacta et cocta in fornace’”, p. 418.

To complicate things further, some texts of the period used “Frankfort black” to refer to lamp black, which opened the possibility that a reader or printer who did not look at the perceived undertone with a critical mind, but who thoughtlessly followed Sowerby’s mixing instructions, might add extra blue to a pigment that already had a bluish undertone.[167]

With regard to the standardisation of the created colours the question arises as to whether all these complications would obstruct the effectivity of Sowerby’s method. Would a different ratio of mixed pigments significantly alter the colours one would perceive? To investigate the aspect of blackness based on different pigment mixes, I decided to perform an extension of Sowerby’s experiments: mixing lamp black with different amounts of red to neutralise its blue undertone, and to mix the brownish Frankforter black with different amounts of blue. In the same sequence I would then gradually diminish the amount of coloured pigment added. To obtain figure 2.7, from left to right I used carmine to lamp black ratio’s of 0:5; 1:4; 2:3; 3:2; 4:1; 5:0; In part c at the bottom of the image, the coloured fringes created when looking through a crown glass prism at these mixtures are visible. I could clearly perceive that the pure red generated some differently coloured fringes compared to the other mixtures. However, already when I mixed in a minor 1/5th of black pigment, the patches generating these border colours became very dark (see figure 2.7a).

According to modern theories, the colours that are generated at the borders of black and white interfaces, should not be influenced by the colour of the patches generating them. These border colours would be fully dependent on the light source, since the light source generates the spectrum of colours separated by the prism.[168] As we have read earlier, Sowerby agrees that light contains the colours, but ascribes a strong agency to the “collecting power” of the black patches, and therefore claimed that the colour of the patches would influence the generated border colours.

When observing the coloured fringes generated by these extreme deviations in mixture, I find it hard to see differences between the fringes of one colour - for instance the red fringes - generated by the different patches.[169] My calculations of the ΔE values also show that there would not be a perceivable difference between the red fringes generated around the first four patches (ΔE between patch 1 and 2: 0,82; between 2 and 3: 1,81; between patch 3 and 4: 1,49). The differences between the red fringes around the other patches should all be slightly perceivable (ΔE between 4 and 5: 4,30, and between 5 and 6: 4,04). For the yellow fringes, differences between all patches should be hardly perceivable (ΔE between patch 1 and 2: 3,27; between 2 and 3: 2,01; between patch 3 and 4: 2,30; between 4 and 5: 4,60; and between 5 and 6: 2,58). It seems that with a constant light source, the fringes that are projected upon the same sheet of white paper used in this experiment show almost no perceivable differences in colour, and therefore are almost independent of the colour of the patches generating them.

The perceivable difference becomes more easily perceivable for the fringes that are (partially) projected onto the patches.The colour perceivable on these patches is the result of a mixing of the colour generated by the light source, and the colour of the patch that shimmers through. The “dark blue” band projected upon the 0:5 carmine patch (see the fringe indicated with a black arrow in figure 2.7), can clearly be perceived as more purplish compared to the other dark blue bands, because the colour of the dark blue band mixes with the red patch that shines through. Also based on calculation, this “dark blue” band is of a clearly distinguishable colour compared to the other dark blue bands (ΔE between 5 and 6: 18,74; between patch 4 and 6: 22,01; between 3 and 6: 21,79; between 2 and 6: 22,75; and between 1 and 6: 24,04). As I remarked above, the pigment mixtures appear to turn black as soon as a very low amount of black pigment is added. Between the other dark patches therefore, the difference in blueness of the “dark blue” bands projected on them is less perceivable (ΔE between patch 1 and 2: 2,48; between 2 and 3: 1,93; between patch 3 and 4: 1,19; between 4 and 5: 3,38).

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[167] Stijnman, “Frankfurt Black: 'Tryginon appelantes, faex vini arefacta et cocta in fornace'”, p. 417.

[168] Pieter Johannes Bouma, *Physical aspects of colour: An introduction to the scientific study of colour stimuli and colour sensations.* Macmillan, 1971, p. 109-117.

[169] In chapter one we have investigated that Sowerby regarded clearly distinguishable bands of colour to be perceivable around black-white interfaces, which he described as a “light blue”, “dark blue”, “red” and “yellow” band. We saw that other savants held other views. Newton for instance regarded the colours to be a continuous spectrum instead of clearly distinguishable bands. For clarity of the references I make in the following analysis, I refer to the fringes in line with Sowerby’s distinction.

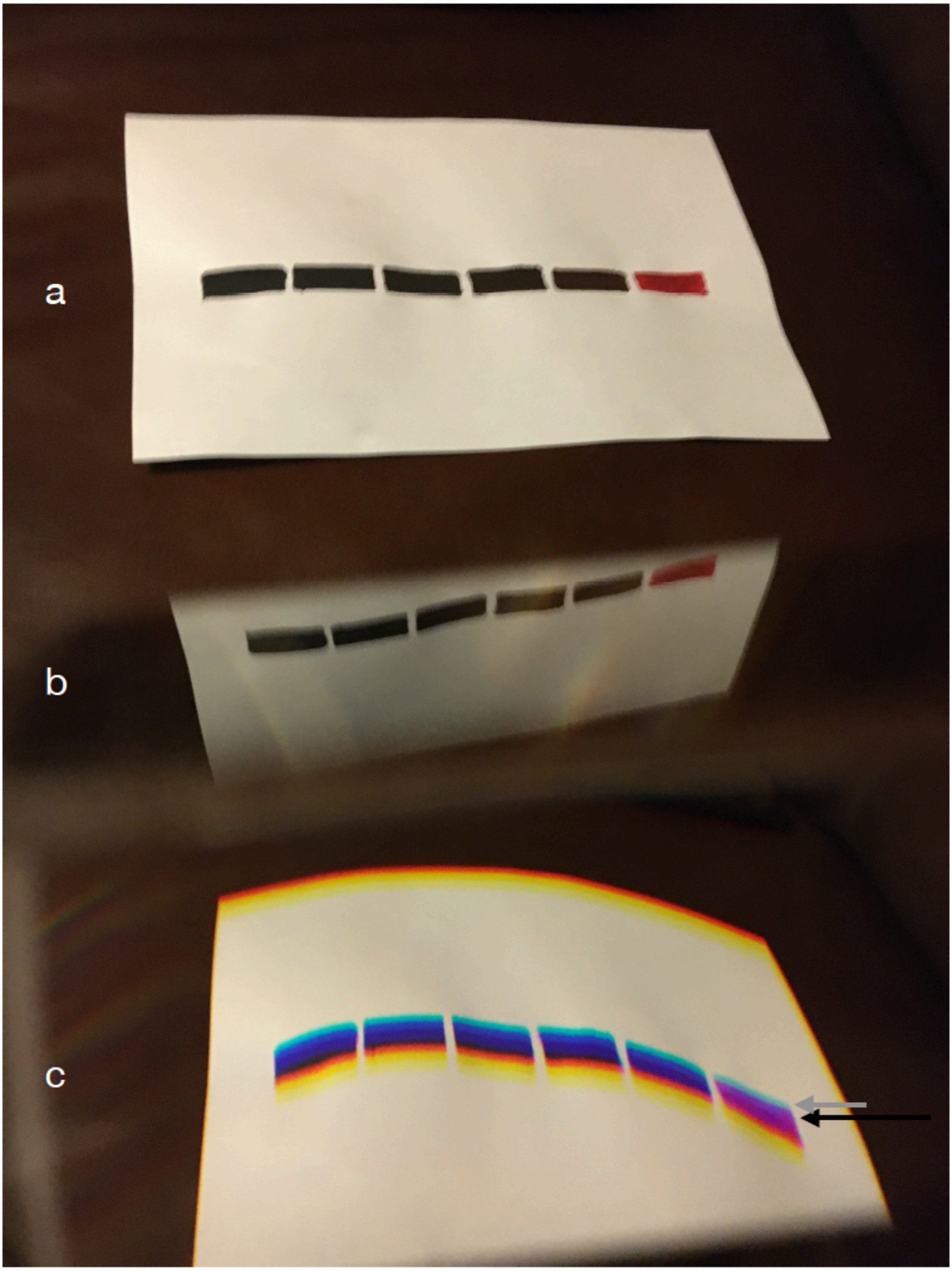

Figure 2.7: Photograph showing a) six paint-outs of the pigment-mixtures of lamp black with carmine, in which the left rectangle is the pure lamp black and the right rectangle the pure carmine; b) the reflection of the paint-outs visible in the prism, and c) the coloured fringes around the paint-outs when perceived through a crown glass prism. (Photo by the author.)

Although it is harder to perceive, part of the “light blue” (see the fringe indicated with a grey arrow in figure 2.7) bands is also projected on the patches, so the red of the red patch shines through in the sixth light blue fringe as well, resulting in high ΔE values compared to the other light blue fringes around the patches (ΔE between 5 and 6: 15,73; between patch 4 and 6: 18,13; between 3 and 6: 16,71; between 2 and 6: 18,83; and between 1 and 6: 22,53).The differences between the light blue fringes around the other patches should be less easily perceivable (ΔE between patch 1 and 2: 4,90; between 2 and 3: 3,12; between patch 3 and 4: 2,38; between 4 and 5: 5,18).

Sowerby does not indicate how the colour of the fringes would be influenced by the redness of the patches generating them, he solely mentions that this reddness will “give an effect to the prismatic tints evidently depending upon the red that produces them,”[170] Looking at the figure in which he depicts red patches and the border colours created upon them, we can observe that his depiction follows the pattern above described: colours projected upon the red patches, will be strongly altered in colour. Therefore, the blue bands are visualised as very purplish, while the colours of the other bands are less influenced by the fact that a red patch is used instead of black (see figure 2.1b).

For the mixtures of Frankforter black with Prussian blue, the same ratio’s and procedure were followed as described for lamp black and carmine (see figure 2.8). While I was mixing the pigments in the intended ratio’s, I perceived the Prussian blue pigment I used to be very dark. After making the paint-outs, all six patches appeared black to me, even the pure Prussian blue patch. Interestingly, according to my measurements of the darkness values (L*), the pure Prussian blue patch is even darker compared to the other mixtures, and the fewer Prussian blue is present in the mixture, the brighter the patch appears (L* patch 6: 2,6; patch 5: 3,56; patch 4: 4,37; patch 3: 5,29; patch 2: 6,03, and patch 1: 7,59). However, on a scale from 0 to 100, this difference in brightness is relatively small. Also based on the calculated ΔE values, there should not be any difference in colour be perceivable between the patches (ΔE between patch 1 and 2: 1,39; between 2 and 3: 1,09; between patch 3 and 4: 1,70; between 4 and 5: 0,65; and between 5 and 6: 1,76). Between the coloured fringes of most of the patches, no or a very hardly noticeable difference in colour should be visible (ΔE between the light blue patch 1 and 2: 1,77; between 2 and 3: 2,18; between patch 3 and 4: 1,17; and between 5 and 6: 1,44; between the dark blue patch 1 and 2: 2,50; between 2 and 3: 2,67; between patch 3 and 4: 0,50; and between 5 and 6: 2,30; between the red patch 1 and 2: 1,00; between 2 and 3: 1,70; between patch 3 and 4: 1,10; and between 5 and 6: 3,8; between the yellow patch 1 and 2: 0,48; between 2 and 3: 1,44; between patch 3 and 4: 0,91; and between 5 and 6: 3,47).[171]

Sowerby indicates that the colours of the fringes created around patches of Prussian blue pigment would not be very different compared to the fringes created around black patches. However, he remarks in his text that “it is however remarkable that the red is more orange than when produced by black,”[172] but he does not depict the red fringes to be more orange in his water colour visualisation of these border colours (see figure 2.1c). I could neither observe the orange colour myself.

Based on my observations and calculations, it turns out that Sowerby’s “colour collecting power” of perfect blackness has little effect if pigment combinations are used to obtain a ‘perfect blackness’, compared to the patches of other, less black mixtures. Only when the colours are projected directly upon a patch that has a strongly deviating colour, such as the full carmine red studied, the colour of the patch will shimmer through the fringes, altering their colour. Regarding all other mixtures I studied in this extension, the ratio’s of lamp black to red and Frankforter black to blue would not have caused the created colours to differ greatly when used for different chromatometers. Especially when a reader or printer would attempt to create a black that would be as black as possible, instead of using the extreme red respectively blue colour-containing ratio’s I experimented with, differences would be hardly perceivable to the human eye.

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170 Sowerby, p. 20.

171 Wat is interesting however, is that between the fourth and the fifth patch, the ΔE’s for all coloured bands should be perceivable (ΔE for light blue: 5.04; dark blue: 3,34; red: 8,0, yellow: 6,98). Inspecting the data, this increase in ΔE is caused by a firm drop in L* values between patch 4 and 5, of around 5,0. Unfortunately, I remain indecisive about the cause of this drop in brightness, and cannot perceive it myself.

172 Sowerby, p. 20.

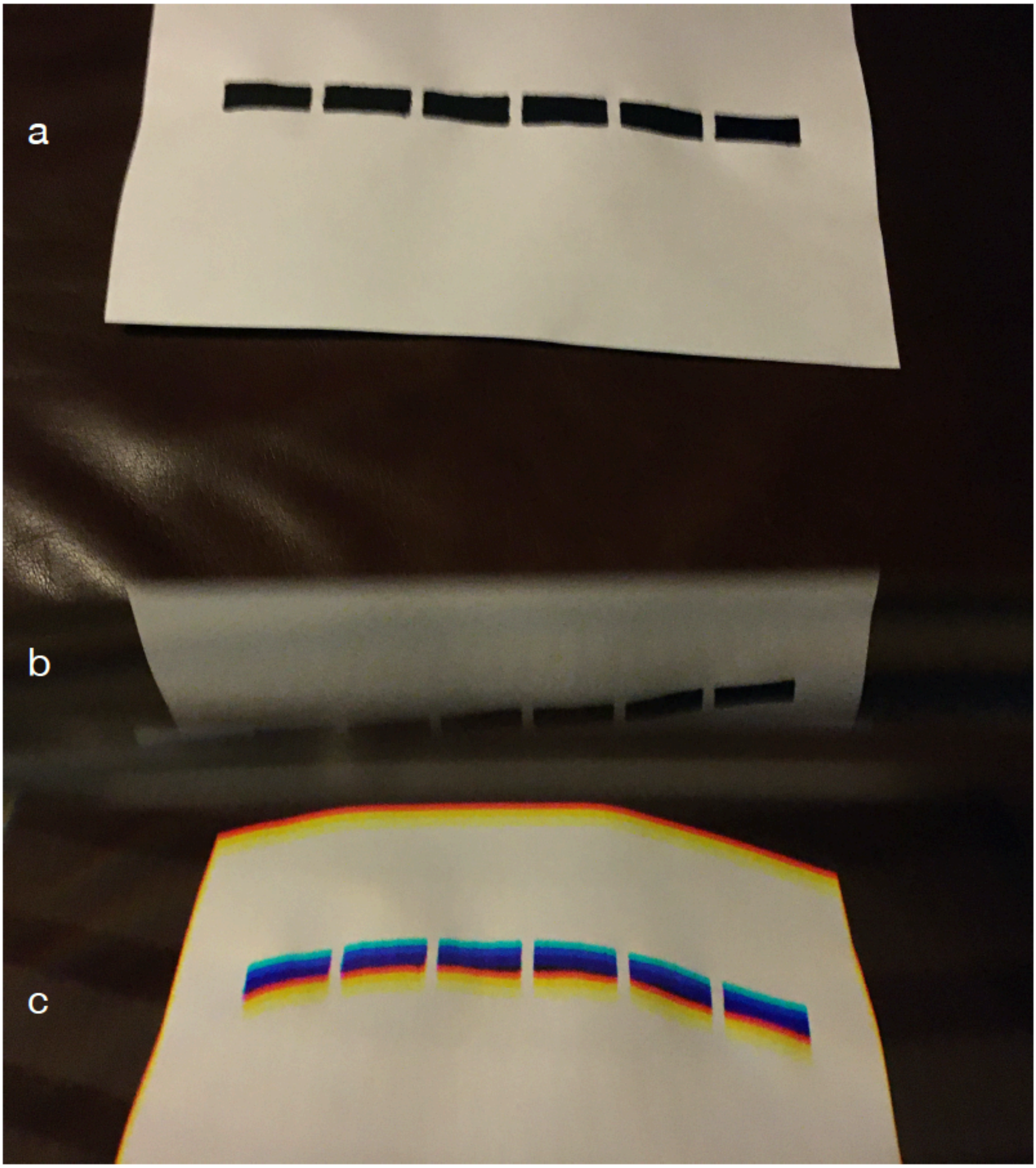

Figure 2.8: Photograph showing a) six paint-outs of the pigment-mixtures of Frankforter black with Prussian blue, in which the left rectangle is the pure Frankforter black and the right rectangle the pure Prussian blue; b) the reflection of the paint-outs visible in the prism, and c) the coloured fringes around the paint-outs when perceived through a crown glass prism. (Photo by the author.)

Prisms

Regarding the type of prism that is needed to perform Sowerby's universally applicable method, he solely writes that one should use a "usual three-sided prism".[173] Would this imply that the type of prism used for Sowerby's experiments is no factor of influence? Or is this an instance in which Sowerby expected his readers to know what specific type of prism to select, without the need to specify it further? In this paragraph, I shall describe the last extension that I will investigate for my thesis: if, and how, different types of prisms influenced the observations of colours practitioners when using Sowerby's chromatometer. Thus, if the type or characteristics of a prism influenced the end-result of Sowerby's method: the determination of colours in a standardised way.

Although Sowerby himself specifies very little about the type(s) of prism one should or could use for performing his chromatometer method, he refers to many sources by other scholars who do address the influence of various aspects of glass (prisms) on creatable spectra. In this paragraph, I shall focus on aspects of prisms that are addressed in the sources Sowerby refers to: the presence of flaws in prisms, and the chemical constitution of the prisms in relation to their refractive and dispersive power. For each of these aspects, I shall first explain what information Sowerby's sources provide. Thereafter, I shall present the results and analyses of our reworkings of Sowerby's chromatometer method with prisms that show variability regarding these properties. And lastly, I shall explain to what extent Sowerby addressed the variation in colours these properties might cause, and provided solutions.

Most of the reworkings presented here, I performed with modern prisms first. However, production techniques and chemical compositions of modern prisms can differ greatly from the production methods and glass compositions in Sowerby's time. The two most important types of glass available in Sowerby's time were crown glass and flint glass (about which I will elaborate in more detail below). Historical flint glass is distinguishable of crown glass by its high concentration of lead. What I was fully aware of, is that in flint glass prisms produced after 1934 - such as the modern prism I used - the lead is often substituted by titanium dioxide and/or fluorine.[174] I wanted to investigate what contemporaries of Sowerby might have seen, and wanted to be sure that differences in coloured bands I might observe were not due to the presence of titanium dioxide or fluorine in the modern flint glass prism I had to my disposal. I needed to find a means to analyse Sowerby's chromatometer through lead containing flint glass prisms, and to compare these observations with prisms that contained less or no lead. Therefore, I arranged to conduct Sowerby's chromatometer method with historical prisms in Museum Boerhaave, Teylers Museum, and the University Museum Utrecht. In total, 38 prisms were investigated: 14 in Museum Boerhaave, 9 in Teylers Museum, and 15 in the University Museum Utrecht. In all of these musea, my collaborator Dr. Hieke Huistra photographed the coloured bands that were visible around a chromatometer through the analysed historical prisms with a Nikon D70s. (For an impression of the used setup, see figure 2.9.) These photographs were colour standardised with a Calibrite Colorchecker Passport Photo 2 and *DarkTable* software. Furthermore, all prisms were thoroughly investigated for the presence of scratches, chipped sides or corners; air bubbles, striae and veins. Ten prisms of the University Museum Utrecht could furthermore be analysed with a portable XRF-spectrometer (Bruker Tracer 5i, with Mudrock calibration, at 15 kV, 25 µA, measurement time 90 seconds) by the Rijksinstituut Cultureel Erfgoed. The raw data of these measurements were analysed with *Artax* software to semi-quantitatively determine their lead content.

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173 Sowerby, p. 16. Based on the colours and breadth of the coloured bands that Sowerby depicted in his figures at the end of the *Elucidation*, I suspect that he used a crown glass prism to perform his experiments with, and that therefore his "usual prism" would have indicated a crown glass prism. However, we shall read below that similar colours and breadths of coloured bands can be created when a flint glass prism is held in an unusual orientation.

174 R. Kingslake and P. F. DePaolis. "New Optical Glasses." *The Scientific Monthly*, vol. 68, no. 6, 1949, p. 422.

Figure 2.9: An impression of the setup used to photograph the chromatometer through the historical prisms held in Museum Boerhaave, Teylers Museum, and the University Museum Utrecht. The chromatometer is placed on the floor between sheets of white paper to prevent influence of the colour of the floor. The photos were made with a Nikon D70s camera on a tripod, 1,5 meter above the chromatometer on the floor. All prisms were held at a distance of 2-12 cm from the camera lens, with one face of the prism aligned with the floor, and the apex angle of the prism perpendicular to the orientation of the camera. (Photo by Dr. Hieke Huistra.)

Defects in glass

Sowerby aspired to develop a method that would foster universally standardised communication about colours, based on the identical border colours different observers would generate when looking at their chromatometers through their prisms. However, Dennis Nawrath has measured how rays of light will be scattered based on defects in glass, altering the rainbow spectrum cast upon a screen (see figure 0.3).[175] The problem of deformed spectra caused by inhomogeneous, imperfect prisms was also noted by Newton, who warned against prisms of bad quality in his *Opticks*, mentioning air bubbles and other "contingent irregularities; such as are Veins, an uneven Polish, or fortuitous Position of the Pores of Glass".[176] During one of his experiments, he points to the negative effect these flaws can have on the created spectra: "viewing the Prism, I found it was full of Veins running from one end of the Glass to the other; so that the Refraction could not be

[175] Dennis Nawrath, "Die prismatische Farbzerlegung durch Isaac Newton." *Kanonische Experimente der Physik: Fachliche Grundlagen und historischer Kontext*. In: Berlin, Heidelberg: Springer Berlin Heidelberg, 2022. p. 41.

[176] Newton, *Opticks*, p. 242; see also p. 41, and p. 71.

regular. I took another Prism therefore which was free from Veins."[177] Since Sowerby studied the *Opticks* in detail, it is very likely that Sowerby was warned for the circulation of flawed prisms. (Furthermore, Newton regarded defects in prisms to be one of the main reasons why some of his contemporaries failed to replicate the results of his experiments.)[178]

To investigate the influence of defects in prisms on Sowerby's method, special attention was paid to features of damage in the prisms of the musea, where the colours they generated on a chromatometer were photographed. In general, two categories of 'flaws' in prisms can be distinguished: damage by usage or storage, and production deformities.

Prisms can become damaged when they are handled: chips can break off the sides and edges of the prisms, and plane sides might get scratched. Almost all the historical prisms we investigated in the musea turned out to be scratched or have chips missing from their sides and/or edges. Only four of the 38 prisms we investigated were entirely scratch and damage free. For the photographs we made, we tried to look through undamaged sides as much as possible. One prism contained scratches on and missed pieces of all three sides, making it inevitable to take photographs through damaged sides. But these flaws do not seem to alter the colours or shapes of the fringes one could generate on a chromatometer noticeably (see figure 2.10).

However, a prism can also be of bad quality due to its production method. Physicist Allexis Rochon (1741-1817), one of the authors Sowerby refers to in his *Elucidation*, describes that many French prisms contained striae of two types:

> Flint glass is brought to us from England in very thin plates. It is blown into globes, which are cut up and stretched out when they have attained to the proper size and thickness. Blown glass will consist of parallel layers, if the workman is not able to take up at once the necessary quantity of matter; and there layers, the junction of which is rarely perfect, will form laminae, that may be easily observed on looking at the edge of the glass. Undulating threads are almost always found also at the joinings of the layers. Opticians distinguish two kinds of these threads, the first of which they call ropes, because they are full and of different densities - they are always prejudicial to the goodness of optical instruments. The second are less troublesome, but more common. They are capillary tubes, which produce two pencils of light in a direction perpendicular to their axis.[179]

When the molten glass is not brought to a high enough temperature, these types of striae can easily form, since the glass remains too viscous to cool homogeneously. Sowerby also mentions this effect in his *Elucidation*: "we may conceive certain undulations, not unaptly represented in the common crown glass of our windows."[180]

During our investigations of the prisms in Museum Boerhaave, and the University Museum Utrecht, we found an example of a prism with severe lamination within the glass: V17851 (see figure 2.11). We were unable to make an undistorted image of the coloured bands visible on a chromatometer through this prism. The "best" result of our attempts can be seen in figure 2.12. Another prism, Li-77, contained two half circles of striation at its sides (see figure 2.13), and generated figure 2.14. Although the chromatometer perceived through this prism looks a bit faint, the image is not perceivably distorted, nor do the colours appear to be very dissimilar to prisms without striation. Two prisms at the Teylers museum, fk-0332 and fk-0332-2 showed slight signs of striation in the glass, but this did not seem to effect the perceived border colours on the chromatometer compared to the prism from the same set that did not contain striae in the glass: fk-0332-1 (see figure 2.15).

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[177] Newton, p. 87.

[178] Simon Schaffer, "Glass works: Newton's prisms and the uses of experiment." In: *The Uses of Experiment: Studies in the Natural Sciences,* edited by David Gooding, Trevor Pinch and Simon Schaffer. Cambridge university press, 1989, p. 94-100.

[179] Allexis Rochon, "III. Observations on platina, and its utility in the arts, together with some remarks on the advantages which reflecting have over achromatic telescopes." *Philosophical Magazine Series* 1, 2:5 (1798), p. 24-25.

[180] Sowerby, p. 15.

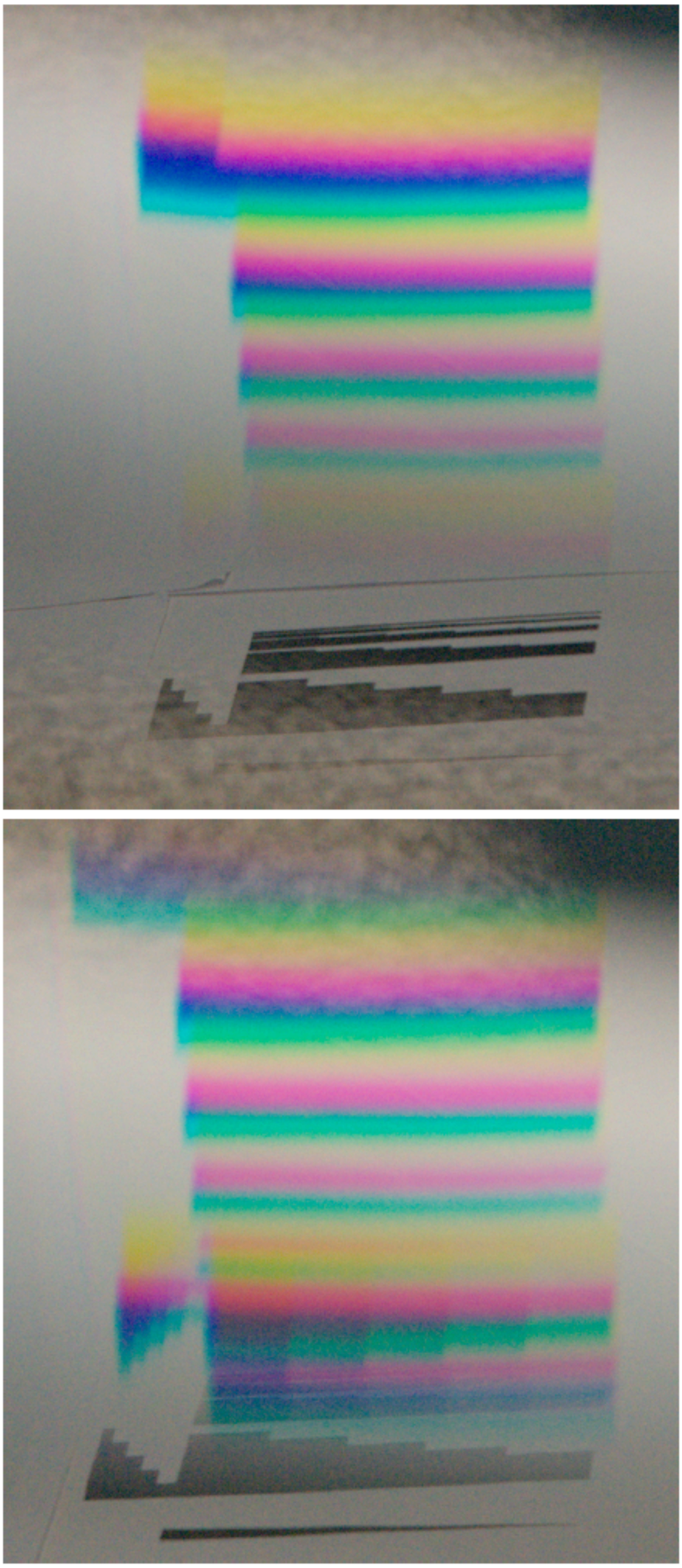


Figure 2.10: Photos of the coloured bands on the chromatometer seen through prism 17718.2 from Museum Boerhaave. Our analysis indicated that the prism was scratched on all three sides, with scratch lengths ranging from 0.5-2 cm; one side missed a large chip, and the other two sides missed small chips. Therefore, we could not avoid photographing the chromatometer through damaged planes of the prism. However, this does not seem to cause perceivable distortions in the generated bands or colours of the bands. (Photos by Dr. Hieke Huistra.)

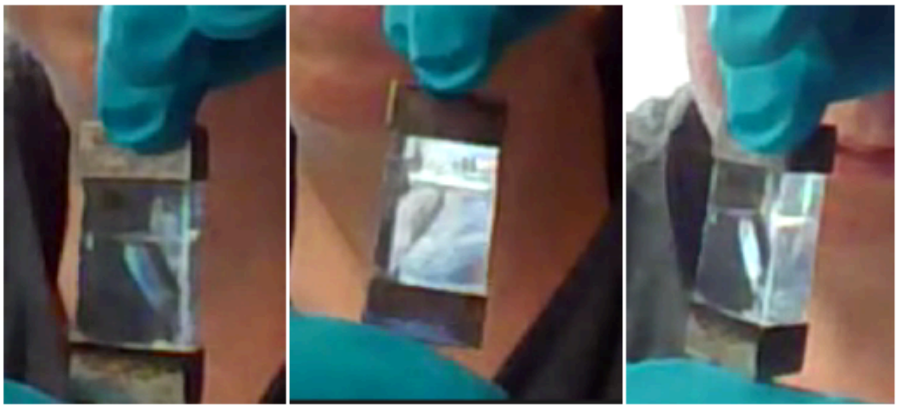


Figure 2.11: Lamination visible in prism V17851. (Photos by Dr. Hieke Huistra and the author.)

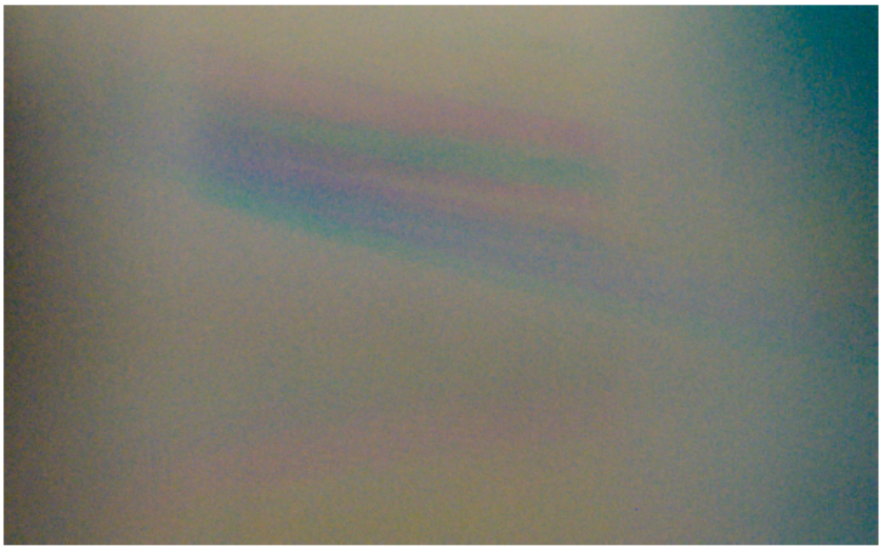
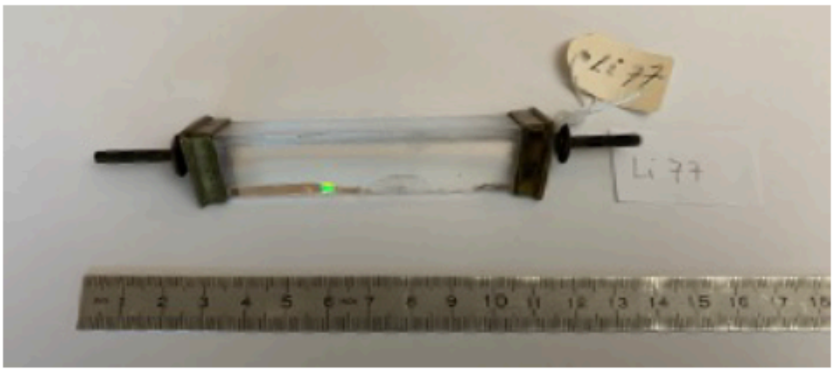


Figure 2.12: Our best attempt to photograph the chromatometer through prism V17851. The orientation of the bottom lines is clearly distorted compared to the orientation of the higher lines. (Photos by Dr. Hieke Huistra.)



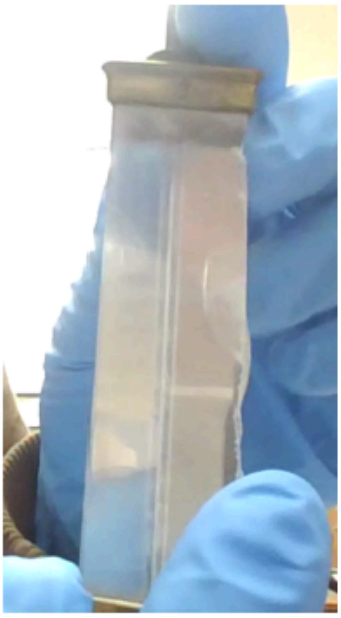


Figure 2.13: Two half circles of striae visible in prism Li-77. (Photo above by the RCE; photo to the right by Dr. Hieke Huistra and the author.)

Figure 2.14: Photographs of the chromatometer through prism Li-77. (Photos by Dr. Hieke Huistra.)

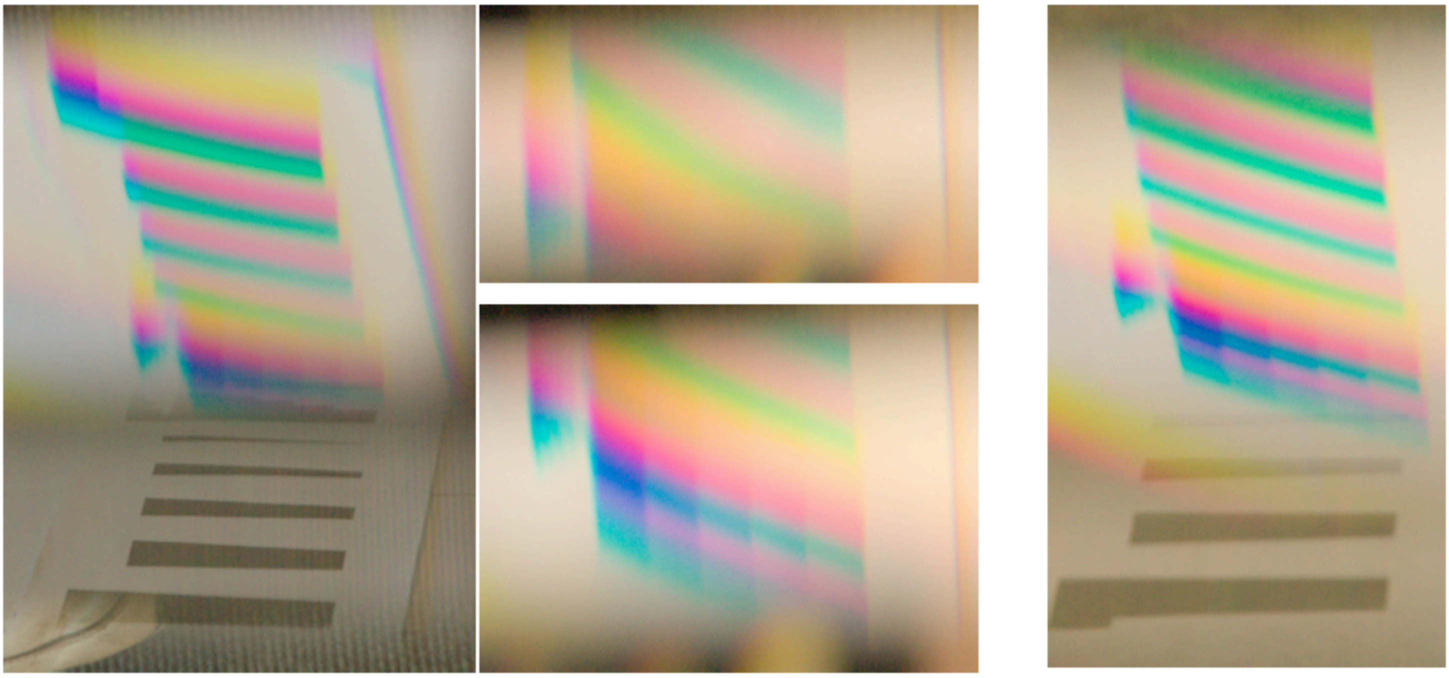


Figure 2.15: Three prisms from the same set in Teylers Museum (“Pair of prism frames with prisms, after W.J.'s Gravenzande (1742)”, likely made between 1750 and 1774).). Two prisms fk-0332 (left) and fk-0332-2 (middle) showed signs of striation within the glass. Prism fk-0332-1 showed no signs of striation. Obtained photographs of the chromatometer appear not to differ based on the presence or absence of striation. (Photos by Dr. Hieke Huistra.)

From every prism of the 38 prisms we analysed, we were able to obtain a photograph of the chromatometer with the coloured bands around the black wedges. Only for the prism that showed lamination we obtained a distorted image of the chromatometer. In all other cases, the damage in the prisms did not influence the orientation or colours of the generated bands perceivably.

Compared to Newton’s account of the abundance of flawed prisms in circulation, the relative good quality of the analysed prisms - besides the traces of handling - is remarkable. In future research, it might be investigated if prism quality had markedly improved by Sowerby’s day; if Newton overstated the amount of troubled prisms around, or if this observation mainly informs us about collecting practices of musea: that only prisms of good quality were kept and thereby preserved for future generations. Or if another or a combination of these explanations is at play.

Dispersive power

We already read above that around 1800 Sowerby’s contemporaries distinguished between at least two types of glass: crown glass and flint glass. However, Sowerby himself does not specify what type of glass prism one should use to perform his chromatometer method with. Is this because he knew that the type prism used would not matter for the performance of his method? Or was he less knowledgeable about the sources he claimed to have studied than he pretended to be? In this paragraph, I shall argue that his lack of specification regarding the type of prism needed is caused by a combination of both possibilities.

In the *Opticks* - of which we are sure that Sowerby has read it, because he paraphrased essential fragments of it in his *Elucidation* - Newton does not elaborate on the influence that different types of glass might have on his experiments: he only mentions to use “a glass prism” to conduct his experiments with, and he does not specify the existence of subtypes. Furthermore, Newton only reports one type of colourless glass (“Glass vulgar”) when listing the properties of various refracting bodies.[181]

Sowerby mentions a source that would have informed him that not all glass (prisms) possess the same optical properties. In his *Elucidation*, Sowerby refers to a paper from William Hyde Wollaston (1766-1828), in which Wollaston explains a new method to measure the refractive indices of various substances, and includes an extensive table containing his measurements on a large array of materials.[182] Among those materials are listed various types of transparent colourless glass and glass-like substances with their refractive indices: Glass, consisting of lead 6

[181] Newton, p. 272.
[182] Sowerby, p. 2; 21; 51.

and sand 1 (1.987); Flint glass (1,586); Old plate glass (1.545); Radcliffe crown glass (1.533); Crown glass, common (1,525); Dutch plate glass (1,517); English plate glass (1,504); French plate glass (1,500); Iceland spar, (strongest 1,657; weakest 1,488); and Rock crystal (1.547).[183]

Although Sowerby only refers to the last part of Wollastons paper in his *Elucidation* (that explains why Wollaston claimed that the solar spectrum can be divided into four colours) Sowerby would have noticed the table if he had actually studied the text. On close examination, however, all the places where Sowerby quotes Wollaston's paper, the quotations are not derived from Wollaston's own lecture, but turn out to be quotations from a paper by Thomas Young, in which Young refers to Wollaston's observations regarding colours.[184] Since Young does not refer to the refractive indices measured in Wollaston's paper, this explains why Sowerby neither refers to Wollaston's method for measuring the refractive indices of different types of glass, nor mentions these types of glass himself in the *Elucidation*.

Based on the content of a paper by Rochon that Sowerby directly quotes in his *Elucidation,* I expected that another property that differs between types of glass - their dispersive power - might influence what one could observe when looking through a glass prism at a chromatometer.[185] Rochon remarked that the lead concentration of glass would influence its optical properties: "what is of most importance to be known here is, that the more lead, or rather minium, is employed in making glass, the more will its dispersive power be augmented."[186] And this strongly dispersive lead glass "in England is known under the name of flint glass."[187] A glass that presents stronger dispersion, would generate a coloured spectrum that is larger than a glass that contains less lead, and therefore the latter disperses light to a smaller extent. This might not seem to be directly related to the colours one would be able to perceive through these prisms. But recall that Sowerby's theory for a large part is built on the idea that red, yellow and blue are the primary colours, and that other colours will be created when bands of these primary colours start to overlap on a chromatometer. If flint glass disperses light to a larger extent, this would generate broader bands on a chromatometer compared to the bands which become visible through a prism that does not contain lead. The expectation is thus, that based on the amount of overlap the colours created on a chromatometer might be different, dependent on whether lead containing or lead free prisms are used.

From Sowerby's theory and method, questions arise about whether it would influence his claim on universally applicable communication about colours if the prism used differed in characteristics, although he did not mention that in his instructions. If lead-containing and lead-free prisms were used on a chromatometer with the same dimensions, would this variation in dispersion cause different overlap patterns to be created? And would a flint glass prism therefore generate other colours on a chromatometer compared to a (lead-free) crown glass prism? Depending on the results of the reconstructions with historical prisms, it could be that Sowerby's instructions need an explicit addition, to preserve the functionality of his statement about universality of his method.

In descriptions of the historical prisms in musea, it is rather the exception than the rule that is mentioned what kind of glass the prism is made of. Luckily, we were able to obtain this information ourselves for ten prisms in the University Museum Utrecht, since we could determine the composition of the glass of with portable X-Ray Fluorescence (pXRF) measurements in collaboration with the Rijksinstituut voor Cultureel erfgoed.

Among the historical prisms we analysed in the musea, nine are likely made of crown glass. For six of these prisms, it could be determined with pXRF that they contained silica (Si), but no lead (Pb), which is in line with the chemical composition of crown glass. These prisms are catalogued

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183 William Hyde Wollaston, "XII. A Method of examining refractive and dispersive Powers, by prismatic Reflection." Read June 24, 1802, p. 370-371. The paper Sowerby quotes from is Thomas Young, "Lecture XXXVII: On Physical Optics." In: *A Course of Lectures on Natural Philosophy and the Mechanical Arts. Illustrated, Etc*, Volume 1, reprint of 1845, p. 340-350.
184 Sowerby, p. 43; 48.
185 Sowerby, however, does not quote the passages about the glass types and their dispersive powers, but Prieur's observations on the coloured fringes visible when studying the moon through a telescope, see Sowerby, p. 47-48.
186 Rochon, Alexis. "XI. Observations on platina, and its utility in the arts, together with some remarks on the advantages which reflecting have over achromatic telescopes." *Philosophical Magazine Series* 1, 2:6, 1798, p. 176.
187 Prieur, p. 176.

as Li-75-01, Li-75-02, Li-83, Li-84, Li-85, and Li-88 at the University Museum Utrecht. An additional 3 prisms have been classified as crown glass in the collection catalogi of the musea, namely UM-5657 and UM-5659 from the University Museum Utrecht, and V22871 from Museum Boerhaave. Many of these crown glass prisms did create a spectrum on the chromatometer that closely resembles what Sowerby described as what one should see when looking through a prism at a chromatometer: a yellow and a red band at one side of the black wedges, and a dark blue and a light blue band at the other side. Furthermore, the bands are all relatively small (see figure 2.16: crown glass - category A).[188] However, contrary to our expectations for lead-free prisms, some crown glass prisms showed broader bands and different colours, and therefore I classified them as a different sub-category of crown glass, to which I will return below.

Of the analysed historical prisms, six are likely made of flint glass. The pXRF analysis detected a high lead concentration within the glass of Li-82 and Li-86, (both having a value of >100.000 ppm), which is in line with the chemical composition of flint glass. Li-6 contained a low amount of lead, ±1600 ppm. Three additional prisms have historically been classified as flint glass, and are therefore registered as such in the collection catalogi, namely UM-5658.02 and UM-5656 from the University Museum Utrecht, and V22870 from Museum Boerhaave. The chromatometers photographed through these prisms clearly show differently coloured bands compared to the category A crown glass prisms: the visible pattern consists of broad alternating pink/magenta and cyan/aqua green bands, between which no black of the chromatometer is visible anymore (see figure 2.16: flint glass). This coloured pattern can be explained by combining the knowledge that flint glass has a much higher dispersive power compared to crown glass, with Sowerby's ideas about how colours will be generated when bands start to overlap. If the coloured bands become very broad, they will be projected over the black patches, making the black imperceivable to the observer. Furthermore, as we read in the paragraph about black and white, when the red band and the blue band start to overlap - since the black does not separate them anymore - the mixing colour magenta will appear. And where the yellow and the light blue bands overlap, a greenish colour will appear. For these prisms, the green is more bluish than yellowish, making them appear aqua green.

Therefore, it turns out that one will perceive very different colours when looking through a crown glass prism, compared to the colours generated by a flint glass prism when these different types of prisms are held under (almost) identical angles and with (almost) identical distances between the prisms and the chromatometer and between the prisms and the camera lens. This difference in prism type seems to cause a problem if one aims to create a universally standardised method to generate colours.

As I already touched upon above, there are also crown glass prisms that generate a different array of colours, which I indicated as category B. These prisms generate bands that are a lot broader compared to the small bands of category A, but that are smaller than the bands generated by the analysed flint glass prisms (see figure 2.16: crown glass - category B). Three of these prisms could be analysed with pXRF. Although they do not contain lead, they turn out to contain arsenic (As): Li-83 (±3800 ppm), Li-84 (±7000 ppm), and Li-85 (±3100 ppm). According to modern literature, arsenic can increase the dispersive power of a prism in a way similar to lead.[189] This explains why these crown glass prisms show a higher dispersion compared to the arsenic-free crown glass prisms from category A, resulting in broader bands that at some points overlap.

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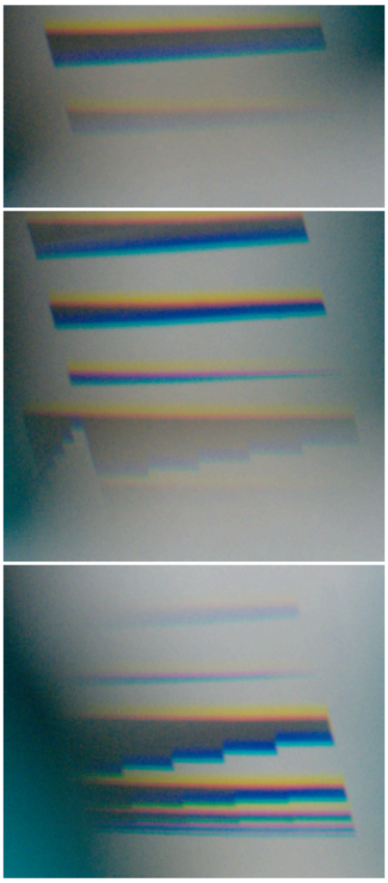
188 The investigated prisms are clustered based on chemical constitution, and show a clear pattern in line with this clustering regarding the bands and colours of the bands visible on the chromatometers. But variables such as angles and size of the prisms might also influence the bands that are perceivable. Information about these additional factors can be provided by the author upon request.

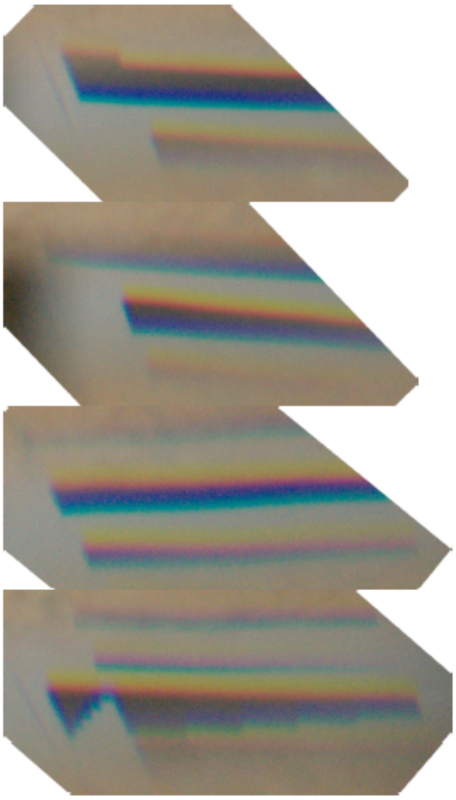
189 Kurt Nassau, D. L. Chadwick, and A. E. Miller. "Arsenic-containing heavy-metal oxide glasses." *Journal of non-crystalline solids* 93.1 (1987): 115-124.

Crown glass - category A

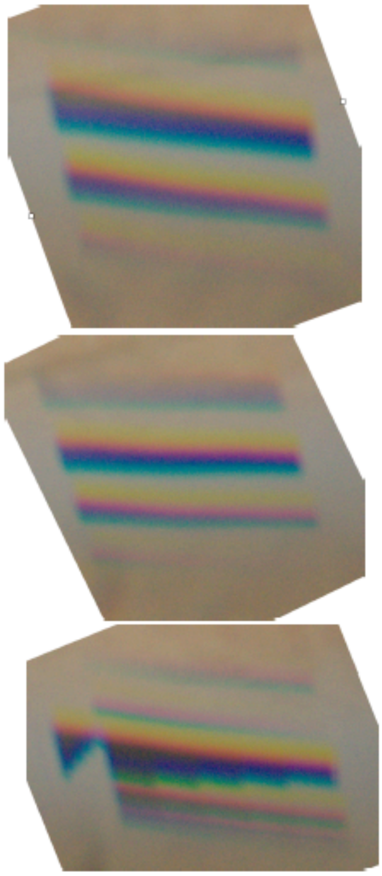
V22871 - Boerhaave



Li-88 - UMU



Li-75.02 - UMU



Li-75.01 - UMU

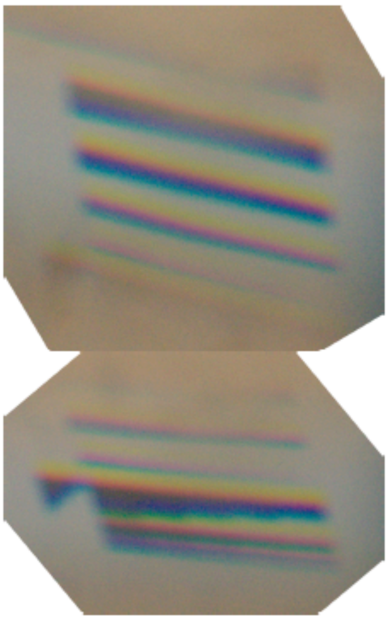
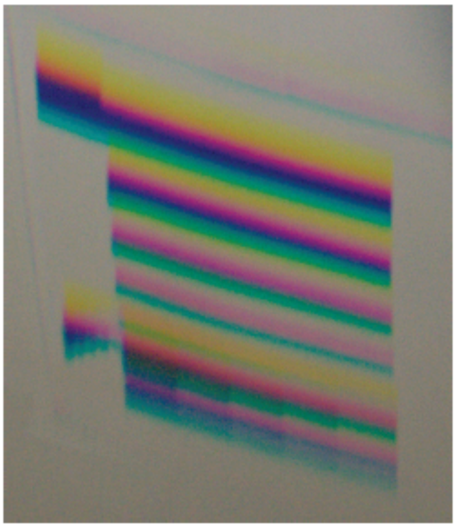


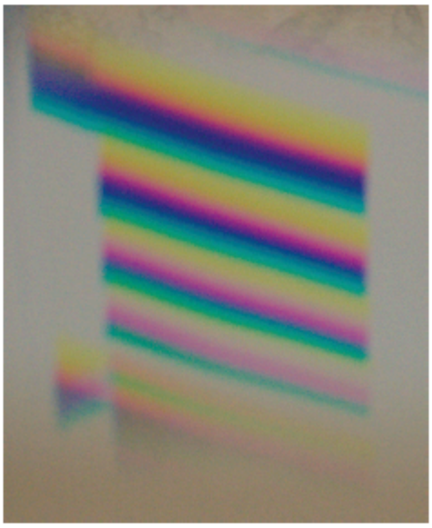
Figure 2.16: Collage of the crown glass prisms - category A - photographed in the musea. The next pages show the collages of the crown glass prisms - category B, and the flint glass prisms. (Photos by Dr. Hieke Huistra.)

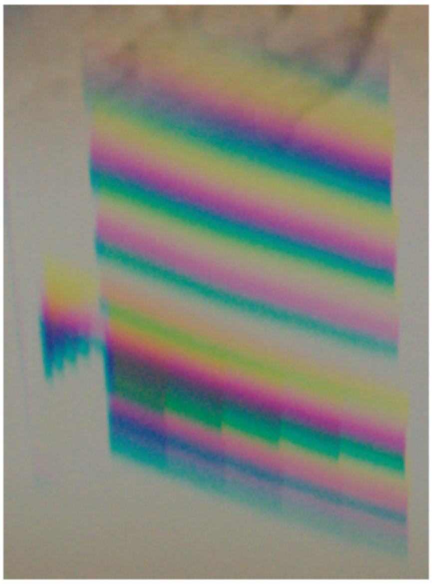
Crown glass - category B

Li-85 - UMU

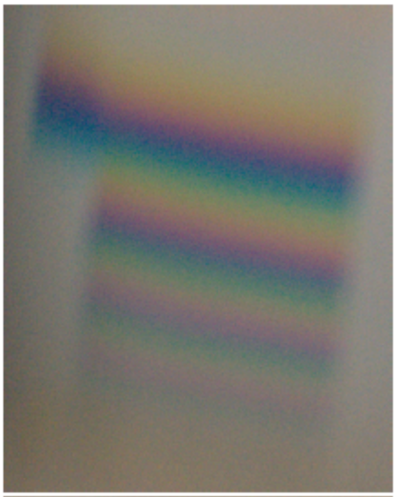


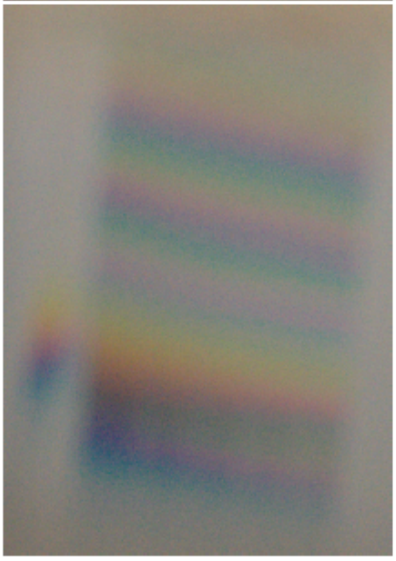
UM-5657 - UMU



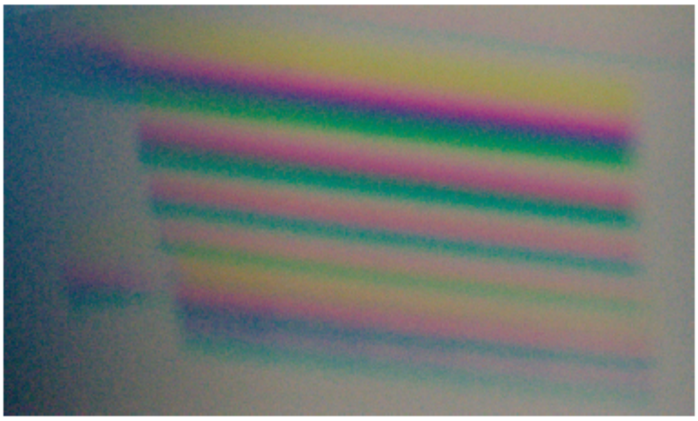


Li-84 - UMU

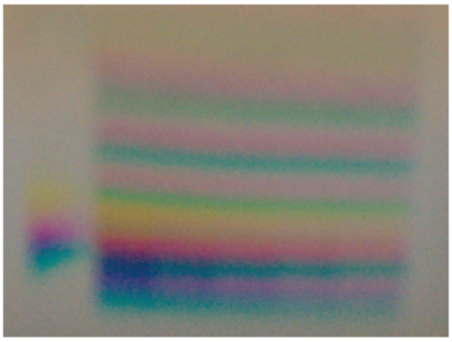




UM-5659 - UMU

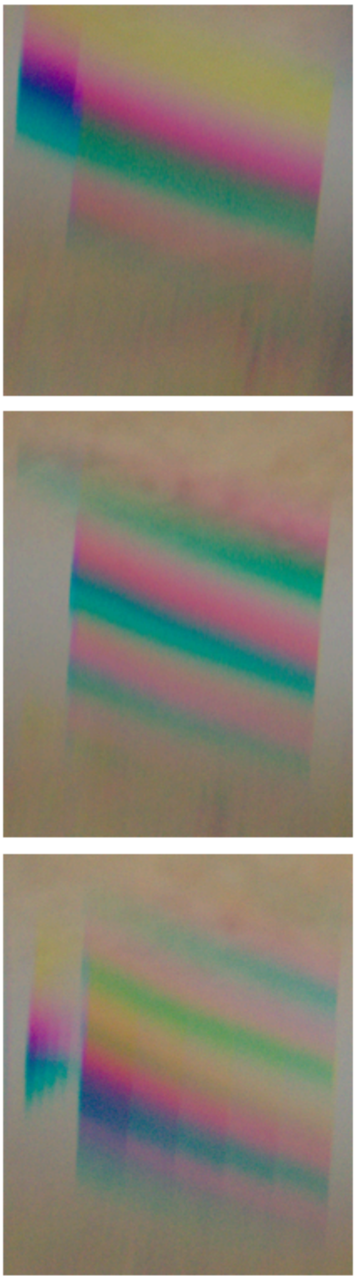


Li-83 - UMU

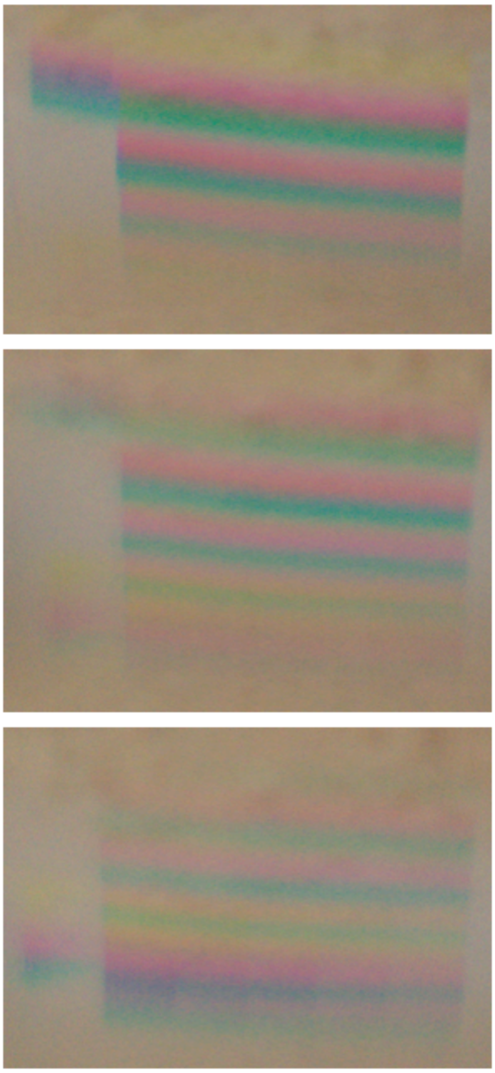


Flint glass

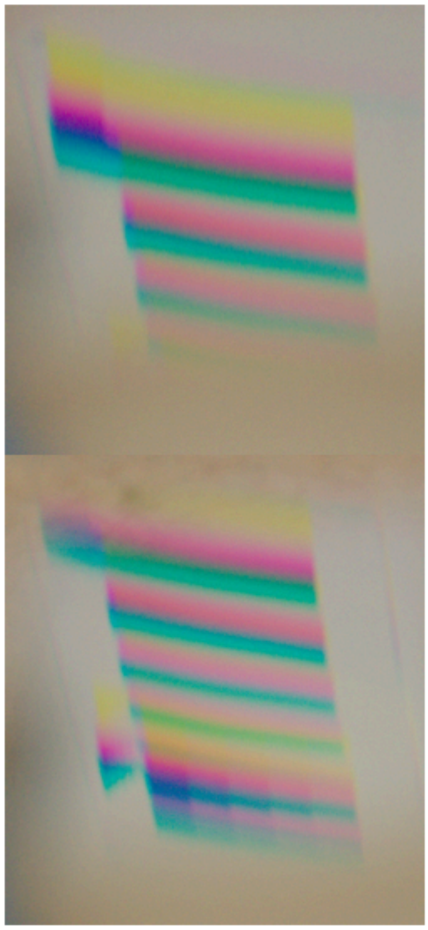
Li-82 - UMU



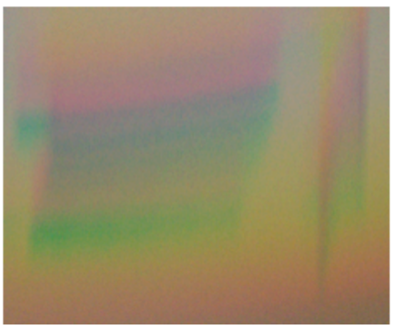
Li-6 - UMU



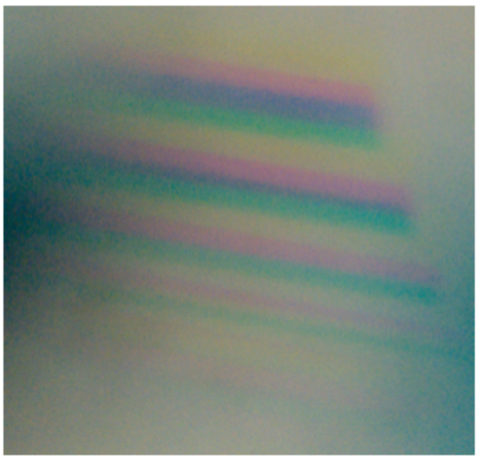
UM-5658.02 - UMU



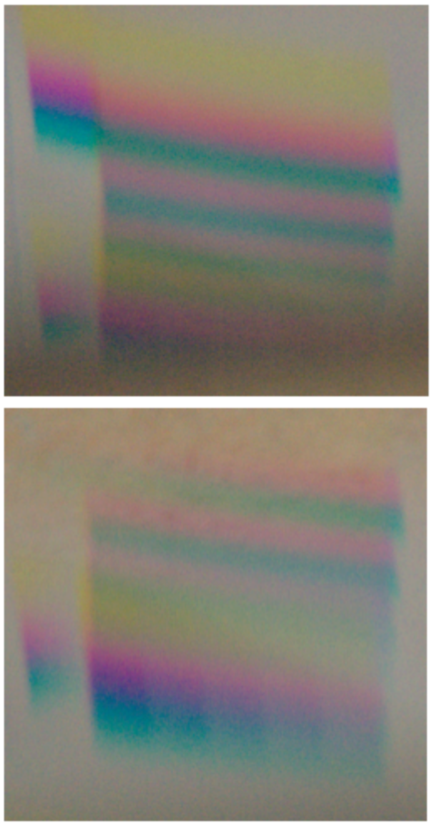
UM-5656 - UMU



V22870 - Boerhaave



Li-86 - UMU



In the analysis above, I already remarked two things. Firstly, that the angles and distances between prism and chromatometer and prism and observer might influence the colours one would perceive through a prism. And secondly, that it seemed that the type of prism used might cause problems for the standardised generation of colours with Sowerby's method, not that this actually would be the case. Sowerby, namely, describes a step in his method that would compensate for differences in dispersive power of various prisms.

Sowerby was aware that the refractive power of a prism might influence the appearance of the coloured bands on a chromatometer.[190] However, this does not lead him to exclude certain types of prisms from usage for his method. Instead, he offers a procedure in which one should vary the distance and angle under which a prism is held, until a certain appearance of the colours red and blue becomes visible on the chromatometer. In this lengthy and at first quite elusive description, he indicates that the black patches produce the colours, but that the distance at which one should perceive the patches varies between prisms, due to differences in refractive power: "but this varies with the refractive power of the prism, wherefore some index is necessary to determine it."[191] Sowerby placed this index at the top left of the uppermost wedge. He continues by describing the colours that one should perceive around this index: "the perfectest red or pale blue to be expected from it."[192] He continues that the generation of these colours is dependent on the orientation of the prism, and that looking at the coloured bands will indicate if one holds the prism correctly:

> Thus when the person has the prism so placed, that the upper edge of the light blue, above the first wedge, is in a right line from the edge of this index, or the dark blue upon it, I expect a similar breadth of scarlet will be at the bottom, adjoining an equal breadth of red under the index.[193]

It is crucial that the following colours are visible: a perfect red and light blue, as well as dark blue above. Next to the index, where the wedge continues, this perfect red should gradually turn scarlet. The coloured bands are not all the same width when seen through the prism, this depends, among other things, on the black space around which they form. (The perfect red should therefore also be visible with a flint prism.) So, by re-orienting the prism, one would be able to change the colour of the bands visible on the chromatometer, until the prescribed colours would become visible. In this manner, one would be able to compensate for the variability caused by prisms with different refractive indices.

At first, I did not believe that Sowerby's instruction to create a red fringe - with whatever prism was used - would actually work. I possessed two prisms with different refractive indices: a crown glass prism with a refractive index of 1.52, and a flint glass prism with a refractive index of 1.62. But the coloured bands that according to Sowerby's descriptions should be red, I perceived as a vibrant pink through my flint glass prism (see figure 2.17). How would turning the prism enable

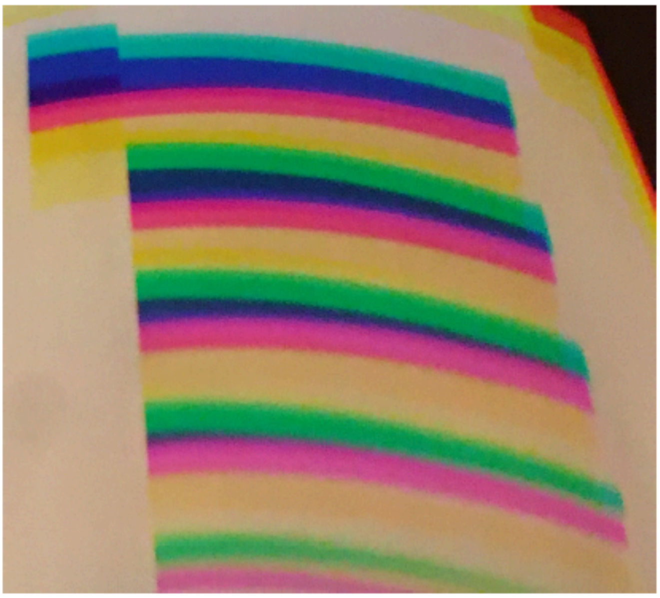


Figure 2.17: Coloured bands visible through my flint glass prism. (Photo by the author.)

[190] In 1880, the first glass was produced that had a high refractive index, but a low dispersion. Before that time, for all glass available there was a positive correlation between refractive index and dispersion: the higher the refractive index of a prism, the more it would disperse light. Therefore, this measuring method would in consequence also compensate for prisms with unknown different dispersive powers; even to the extent of overlap and colour of the bands visible on a chromatometer. See Kingslake and DePaolis, p. 420-421, in particular figure 1.
[191] Sowerby, p. 25-26.
[192] Sowerby, p. 26.
[193] Sowerby, p. 26.

me to transform these pink bands into red ones? Despite my disbelief and preconceptions, I decided to take Sowerby's instruction seriously, and started turning and moving the prism in all possible directions. Varying the angle did not appear to have the desired effect, nor did changing the distance between my eye and the prism. However, thereafter I decided to change the comfortable position I had been sitting in - with my back straight and only my head turned downwards to the sheet of the chromatometer - into a pretty uncomfortable position in which I bent very closely to the chromatometer. At first I could not believe what I saw: the pink band slowly obtained a reddish tinge that became more apparent the closer I moved to the paper, until at last the band appeared red to me. It looked to me even more vibrantly red, compared to the red fringes I had been perceiving through my crown glass prism (see figure 2.18). Therefore, I subsequently tried to turn my crown glass prism to perceive a red fringe that was as vibrant as that visible through the flint glass prism (see figure 2.19). Unfortunately, to date I have not succeeded in this attempt. To create similar fringes, the crown glass prism needed to be held at a much larger distance, but at an increased distance the brightness of the fringes decreases. Although I therefore have not been able to perfectly standardise the colours visible through these different types of prisms, I do not exclude the possibility that with more practice and experience this would become possible.

The above described discovery, that the colour of the perceived fringes can be changed by varying the distance and angle between one's eye, the prism, and the chromatometer, is of influence on the analysis of the photographs made of chromatometers through different types of (historical) glass prisms. It might be the case, that the visible colours created by the various prisms could be made more alike by varying these distances and the angle for each prism. However, to capture legible images of the chromatometers through both the historical prisms and an additional set of camera lenses proved to be a difficult and time consuming task on its own. Investigation of the possibility to create similar border colours through all of these prisms, and the capture of these effects for analysis, therefore remains to be done in future research. For this thesis it suffices to clearly have visualised the difference in generated colours with flint and crown glass prisms, and the difficulty in obtaining a similar intense red colour with a flint glass prism. This provided insight in the colours that these prisms would generate on a chromatometer. Furthermore, it made me aware that if one would use a flint glass prism or a prism containing arsenic to perform his method, paying attention to this calibration step with the help of an index would be of key importance to generate the desired colours.

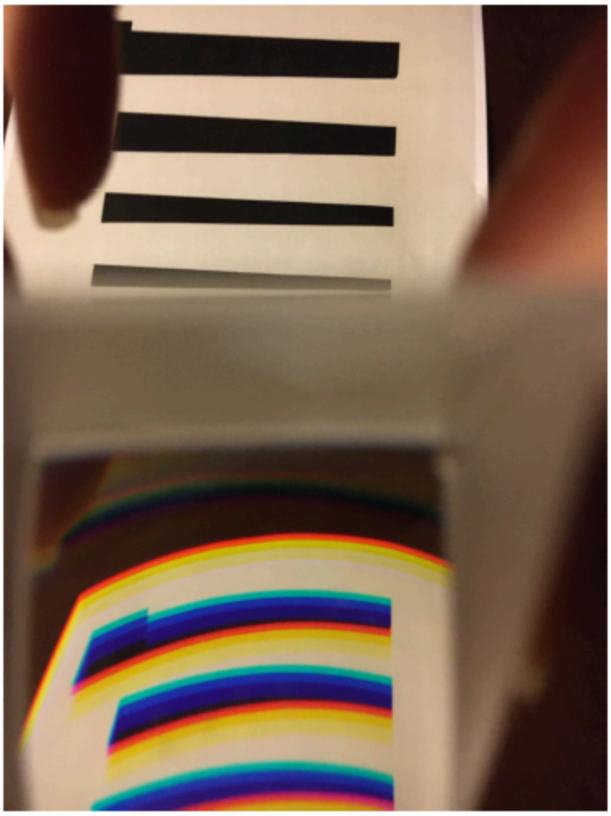
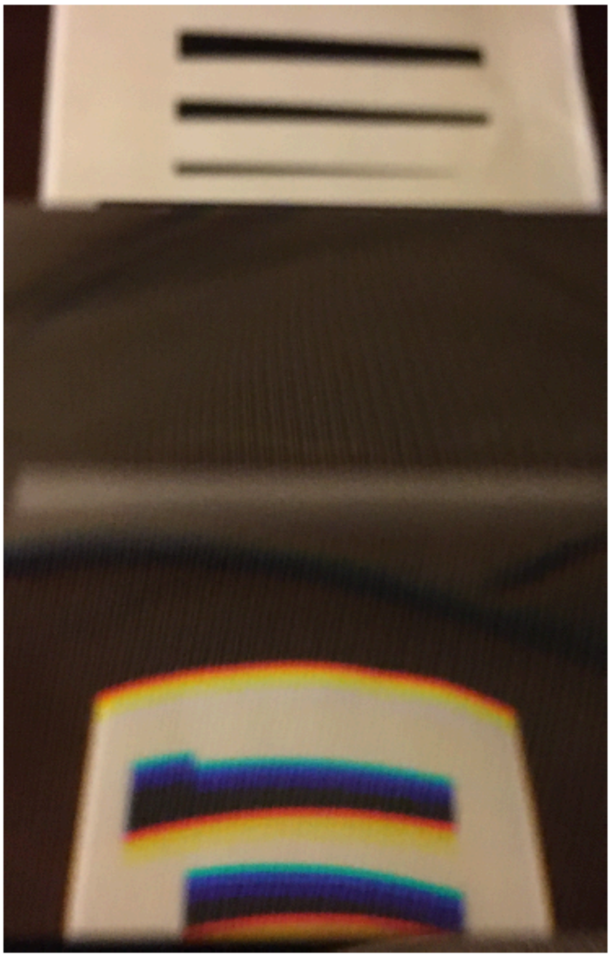


Figure 2.18: Coloured bands visible through my flint glass prism when moved closer to the chromatometer (left). Position of the flint glass prism above the chromatometer to perceive these bands (above). (Photos by the author.)



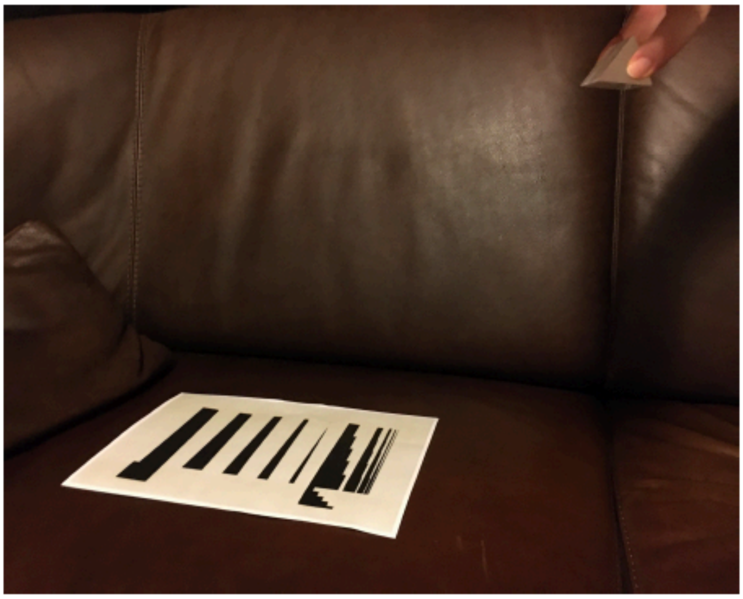


Figure 2.19: Coloured bands visible through my crown glass prism (left). Position of the crown glass prism above the chromatometer to perceive these bands (above). (Photos by the author.)

Conclusion

The renowned engraver James Sowerby was extremely disappointed in the instability of pigments that in his day were used to hand colour depictions of minerals and plants. He intended to develop a method to communicate about colours in a standardised way, that could be adopted universally and until the remotest ages, based on fixed colours that would never fade.[194] He ridiculed his contemporaries who remained in the domain of pigment based colours, since the colours one could generate with a prism by separating white light into its constituents was much more durable.[195] However, light alone was insufficient to generate the boundary colours Sowerby was looking for. As he theoretically explained, one needed a means to create contrast between black and white to make these colours perceivable. To construct his chromatometer - the object with which all imaginable colours and their tints would be generatable - he therefore prescribed to paint black patches on a white paper, using pigments. Sowerby regarded the stablest black pigments available to him to have an additional problem: they were not intensely black enough to create the perfect colours Sowerby aimed for. This lead him to experiment with various pigment mixtures to create the blackness he desired. In this way the foundation of Sowerby's method does not differ much from the attempts to improve pigment colour and stability of his predecessors and contemporaries.

Reconstructing Sowerby's method with various mixtures of the prescribed pigments, it turned out that the blackness of the mixtures hardly influenced what boundary colours were created at a perceivable level. But if a coloured band overlapped with the patch of pigment, the perceived colour would be a mixture between the light rays refracted to that position and the underlying pigment shimmering through. For pure red or yellow patches of pigment, this would create coloured bands that deviated from Sowerby's three primary colours. And the same problem would occur if a band of coloured rays was projected upon a paper with a darker or tinged colour compared to the perfect white Sowerby had in mind.

These effects that compromise the standardisation of the coloured fringes generated would be eliminatable if everyone around the globe would use exactly the same white paper, and painted exactly the same black patches upon it, for which everyone used the same base pigment mixed in the same ratio. But Sowerby intended his method to facilitate communication about colours that could not be physically transferred. So, how would savants around the globe be able to communicate about the base materials they should use to create a chromatometer in advance of their possession of a chromatometer? How could they check and verify that the colours of their devices were the same, without seeing each others chromatometers? Sowerby's answers would be simple: they could all buy a chromatometer at his local printer, who could check that all papers and pigments were of the right grade of blackness and whiteness. Sowerby furthermore provided advice on the best storage conditions, to ensure that the chromatometer would remain valid for some time. At the same time, however, Sowerby's awareness of the degradation of a chromatometer in time alarms us that he knew that his method, just as pigment depictions, suffered ageing problems.

Against these criticisms, the standardisation of generated colours that could be achieved when savants used different types of glass prisms is impressive. As I shall elaborate in more detail in chapter three, the breath of the generated coloured bands was of no importance to Sowerby, and therefore the difference in dispersive power of various types of glass would be unimportant for the working of his method. Flawed prisms, furthermore, would hardly cause perceivable distortions in the visible spectra on the chromatometer.

At my first reading of Sowerby's *Elucidation*, I expected that the lack of specifications regarding the distance and angle at which one should hold a prism were a weakness of his method. But following his text closely for my reconstructions, it turned out to be one of its strengths. The variability in colours visible through various shapes and types of glass prisms can to a large extent be eliminated by varying the distance and angle at which a prism is held. However, communication about the "ideal" colours one should perceive, and with which one could check the right orientation and placement of the prism in relation to the chromatometer and ones eye, should again be done in advance of the usage of the chromatometer method.

Communication about the materials that are needed to perform Sowerby's method turn out to be essential for its working. But even if successful communication regarding the materials one should employ had been established, and everyone possessed the same coloured white

194 Sowerby, p. 27.
195 Sowerby, p. 46.

paper, with the same deep black patches upon it, and used an identical prism to create border colours with, would that be sufficient to let people communicate in a standardised way about colours? To these questions, we shall turn in chapter three, where I explain the method and results of a participant study about the working of Sowerby's method.

Chapter Three: Participant study

> I now enter upon a curious subject; and I presume that even after what has been said and done, it will appear at first a sort of chimaera for a parcel of dark unintelligible forms to give a most exact account of the proportion of colours. Having in the preceding part shown in what manner colours are produced by means of the proportions of black upon a white ground, or white on a black ground, this is intended to serve as a lasting means of proving the hypothesis, or as a test for any particular tint, under whatever impression we wish to form a comparison.[196]

With these words, James Sowerby introduces his invention that would enable universal communication about colours "until the remotest ages" to his readers: his *chromatometer*.[197] Even after the description of how colours can be generated when one looks through a prism at black-white intervals on paper, which he explained in foregoing experiments in his book *A New Elucidation of Colours* (of which some have already been analysed in detail in the previous chapters of this thesis), he realises that the chromatometer that forms the crown of his work might still seem a "chimera" to people interested in his method, making use of "unintelligible" forms.

In brief,[198] the chromatometer, a piece of white paper with black wedge-shaped and staircase shaped forms on it, works as follows:

> This wedge therefore produces an infinite variety of these three primitive tints [e.g. red, yellow and blue], from the most full and perfect to the most dilute, which may be measured precisely at pleasure in a very certain manner; so that every person may, in a common light, agree in pointing out a precise tint, even at distant parts of the world, if a similar wedge or chromatometer is used.[199]

As has been shown in the previous chapters of this thesis, the use of precisely described, standardised materials to perform his method is crucial for the success of Sowerby's method, since deviations in this regard can cause huge deviations in the observed colours.

In the introduction to this thesis I already described that Sowerby, despite that he himself acknowledged the difficulties to be encountered when one used his method, was convinced that his method of using a chromatometer to foster universal communication about colours was not only teachable, but would also lead to universally standardised results: "this scheme is in its nature perfect, and calculation, measure, &c. will prove it; but how far the limited powers of mankind will carry it, remains a desideratum."[200] I therefore not only examined the material variables that influence the succes of Sowerby's method in my thesis, but also the human and communicative aspects connected to his chromatometer: Is Sowerby's method teachable to other people? And if this is indeed the case, would that also in this "remote age" generate standardised, transferable results among performers of his method?

"Teachable" in this study is defined as: how easily participants are able to perform the sequence of actions as Sowerby describes, generating the observations Sowerby intended one to see. Or, operationalised: how much extra help from the instructor participants needed to perform

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196 James Sowerby, *A New Elucidation of Colours*, p. 25.
197 Sowerby, p. 5.
198 In previous chapters has already been described in detail who Sowerby was, what his objectives were, what his chromatometer looked like, and how his method worked. The necessary information about the chromatometer and its intended usage to understand the study presented in this chapter, will be given in more detail in the paragraphs describing the experiments participants performed, which can be found in the "participants, materials and methods"-section below.
199 Sowerby, p. 27.
200 Sowerby, p. 30.

the method correctly and obtain the desired results.[201] Were they able to generate the desired results at all? And how much time did it take them to do so?

Sowerby envisioned his method to work as follows: an observer of for instance the red chest of a robin, would take a prism at hand and look through it at the chromatometer. Amongst the various colours and tints generated on this device, the observer would pinpoint the exact location at which this tint of red matched the red seen on the chest of the robin.[202] This location would thereafter be measured, and communicated to another natural philosopher or artist. The receiver of this information would take his or her own chromatometer, look at the communicated location on it through a prism, and would in that way be able to observe exactly the same colour and hue as the observer had seen on the chest of the robin. However, the observer and receiver would need to know how to generate colours and tints on the chromatometer in the right way before this kind of communication would be possible.

Before I detail the participants study I myself performed, it might be insightful to give some information about what we know about Sowerby's own attempts to teach his methods to others. Sowerby himself performed optical demonstrations with prisms for a large public. However, from the written invitation to these performances we can infer that the twenty people who could attend a session were expected to stay seated and admire the spectacle that Sowerby presented to them from a distance.[203] Sowerby does not mention anything about providing his attendees with a prism so they could try to generate the presented observations themselves, nor that he intended to actively teach his method to them. This might be one of the reasons why to date no records have been found of other people engaging with Sowerby's method during his lifetime.

To my knowledge, the only person who has previously invited people to try to perform Sowerby's method is the historian of science Paul Henderson. Although Henderson did not investigate the teachability and extent to which Sowerby's method lead to standardised results, the playful way in which he asked people to use Sowerby's method provided me with insightful information for the design of my own participant study. He undertook this occasional class for the festive second "Burlington House Courtyard Summer Late" in 2017, a day at which the Royal Academy of Arts, the Society of Antiquaries, the Royal Astronomical Society, the Geological Society, the Royal Society of Chemistry and the Linnean Society together presented information about the history of the sciences and the arts to the public. He asked visitors to take a prism at hand, and try to visualise colours with this prism on a chromatometer that was attached to a board (see figure 3.1 on the next page).[204] Henderson directly confronted the visitors with the chromatometer, without beforehand training them with some less complicated experiments of Sowerby. According to Henderson, visitors regarded it to be "good fun but jolly difficult to get really meaningful results."[205]

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[201] "Obtaining the desired results" was only analysed for experiments one to three, since for these experiments Sowerby clearly describes in his book what he intends observers to see. For experiments four and five, instead, Sowerby does not himself mention intended outcomes. Therefore, in these experiments there were no right or wrong answers possible.

[202] A note on terminology: there are various terms related to the variant of a colour one can perceive, among which are "hue", "tint", "tone" and "shade". A "hue" of a colour is related to the extent to which a colour is mixed with another colour. So, for instance a green can have a bluish hue or a yellowish hue over it. "Tint" is related to the amount of white added to the colour thus lightening the colour. "Tone" is related to the amount of grey added to the colour, and "shade" to the amount of black added. On Sowerby's chromatometer all colours become paler, i.e. whiter, along with diminishing thickness of the black productors generating the fringes. Sowerby himself therefore predominantly uses the word "tint" to describe the gradations of paleness on the chromatometer. In concert, in this study the different variants of a colour perceivable on the chromatometer based on the gradual whitening are also named "tints".

[203] "3-2: Prospectus of *A New Elucidation and Arrangement of Colours*," and "3-3: Notice of Sowerby's Chromatometry lecture." 1 December 1808. Manuscript letters to members of the Sowerby Family: Box 5: Unattributed and Miscellaneous, DM1186 - Eyles Collection relating to the history of geology, Special Collections, University of Bristol Library.

[204] Alicia Fernandez, and Isabelle Charmantier, "Colours of Burlington House – A Chronicle." *The Linnean Society of London*, 16 August 2017, https://www.linnean.org/news/2017/08/16/16th-august-2017-colours-of-burlington-house-a-chronicle. Accessed 21 October 2023.

[205] Paul Henderson, personal communication.

Figure 3.1: A visitor tries to see the coloured fringes on a chromatometer hanging on a board, being supervised by Paul Henderson (right). (Image reproduced with courtesy of the Linnaean Society.)

In order to study the teachability of Sowerby's method in more depth, and hopefully obtain meaningful results from it, in this study I have chosen to introduce Sowerby's method to participants in a step-by-step manner: first, they were asked to perform a selection of less complicated experiments Sowerby describes in his book. Therewith, participants were introduced to Sowerby's way of thinking, observing, and working with this method. Only once participants had successfully completed this learning trajectory, they were asked to turn to the chromatometer itself, and try to code and decode colours and colour descriptions based on his method.

Educational group experiments by Nawrath and Huistra et al. have also shown that when participants are asked to rework historical optical experiments - in both cases reconstructing the *experimentum crucis* of Newton's *Opticks* - this often turns out to be more complicated than it might seem at first sight. Nawrath's research has shown that reworking the experiment is theory-laden: most students analysing the experiments do not perceive details that are not in agreement with Newton's theory.[206] Huistra et al. asked high school students to rework Newton's experiment under historical lighting conditions, which taught them how difficult replication of Newton's observations must have been for his contemporaries. Of particular interest for this chapter is, that they let the students experience that there was a huge difference between reading what Newton described to be his experiment, and actually performing it. Hardly anybody of their participants turned out to be able to rework the experiment in the same way as Newton had claimed to have performed it.[207] Based on my own reworkings of Sowerby's experiments, I expected that Sowerby's descriptions of his experiments might also cause problems of interpretation to participants. In the "participants, materials and methods" section of this chapter, I will elaborately discuss how I operationalised Sowerby's method for this study, and how the instruction presented

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[206] Nawrath, D. "Die Analyse von Newtons Prismenexperimenten zur Untersuchung von Licht und Farben (1672) - Ein Erfahrungsbericht." In: O. Breidbach, P. Heering, M. Müller, & H. Weber (Eds.), *Experimentelle Wissenschaftsgeschichte,* München: Wilhelm Fink Verlag, 2010, p. 95. See also Nawrath, D. "Auf den Spuren Newtons - Experimente zur Farbzerlegung und Farbmischung mit Prismen." *Naturwissenschaften im Unterricht Physik* 110 (2009), p. 16-20.

[207] H.M. Huistra, T. Cocquyt, H.N. Asper and T. van der Valk, "Proeven van Vroeger: Een ANW-module wetenschapsgeschiedenis", *NVOX* 37 (2012), 422–424.

to the participants is related to Sowerby's initial descriptions and theoretical assumptions. But first, I will set forth the selection criteria for participants of this study, and the environmental conditions under which the sessions with participants were performed. In the "results and analysis" section, I will analyse the performance of the participants in order to determine to what extent Sowerby's method turned out to be teachable within the setup of this study. And lastly, I shall analyse if the results participants generated when using Sowerby's method to code and decode colours indeed would foster universal communication.

This research has been approved by the FETC-GW – the ethical committee of the Faculty of Humanities at Utrecht University, FETC-H reference number: 23-074-02.

Participants, materials and methods

Participants

For this study, participants were asked who had some affinity with Sowerby's nineteenth century qualification of "natural philosopher investigating colours". Therefore, students and PhD candidates connected to the History and Philosophy of Science master at Utrecht University were recruited, as well as students and PhD candidates connected to the Chemistry department who had a strong affinity with optics.

As to the selected age range of participants, studies have shown that colour discrimination gradually deteriorates with age. Although the short-wavelength-sensitive cones (S-cones) in the eye, which are related to colours on the blue-yellow axis are more severely influenced by age, degradation has also been reported for the medium/long-wavelength-sensitive cones (M/L-cones), which are related to colours on the red-green axis. For instance pupil size, crystalline lens coloration, and macular pigment density can influence the colours one perceives.[208] Furthermore, it has been determined with various colour-tests during multiple studies that colour discrimination is best between 20 and 40 years of age, and gradually declines thereafter.[209] In order to be able to investigate the extent to which Sowerby's method itself leads to standardised results, and to exclude, as far as possible, the influence of age on colour determining tasks, only subjects aged between 20 and 40 participated in this study.

40% (N=4) of the participants was male, and 60% (N=6) were female. Since women were neither allowed to study at British universities at the beginning of the nineteenth century, nor were they allowed to participate in learned societies as The Royal Society of London, one might wonder if Sowerby intended women to be included amongst the natural philosophers who would correspond about colours based on his methodology.[210] However, studies have shown that women could be active for instance in scientific networks as collectors of specimens such as minerals, plants and animals.[211] Even more relevant, Sowerby himself also actively corresponded with women collectors about specimens, and he has thanked many of them explicitly in his publications for their contributions to his work.[212] Furthermore, in the Lambeth Chemical Society where Sowerby was the treasurer, women were allowed to attend the demonstrations given.[213] Therefore, Sowerby's correspondence network, and in consequence the audience he aimed at for the use of his method, would have included women as well as men. So, to design a representative study, both male and female participants were invited to participate in the experiments.

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[208] Yokoyama, Sho, et al. "Age-related changes of color visual acuity in normal eyes." *Plos one* 16.11 (2021): e0260525.

[209] Roy, Monique S., et al. "Color vision and age in a normal North American population." *Graefe's archive for clinical and experimental ophthalmology* 229 (1991): 139-144; Yokoyama, Sho, et al. "Age-related changes of color visual acuity in normal eyes." *Plos one* 16.11 (2021): e0260525.

[210] Schiebinger, Londa. "The Philosopher's Beard: Women and Gender in Science." *The Cambridge History of Science*, edited by Roy Porter, vol. 4, Cambridge University Press, Cambridge, 2003, p. 186-187;189.

[211] Schiebinger, p. 188.

[212] See for instance Sowerby, *British mineralogy, or, Coloured figures intended to elucidate the mineralogy of Great Britain*, vol. 1, 1802, p. 14; 82; 84; 171; 192; 205-206.

[213] Paul Henderson, *James Sowerby: the enlightenment's natural historian*. Royal Botanic Gardens, Kew, 2015, p. 276.

Since Sowerby hoped that his method would foster communication about colours between people all around the globe, international students (50%; N=5) as well as Dutch students (50%; N=5) were invited.

Studies have led to contradictory results with regard to the relationship between a need for wearing glasses or lenses and participant performance in colour discrimination and colour naming task.[214] Furthermore, it has never before been investigated if people with lenses or glasses focus differently when looking through a prism at a chromatometer, and if this influences their learning trajectory and/or the distances at it where participants perceive a certain colour. However, by studying the portrait Sowerby commissioned in 1816 - seven years after he developed his method - one can see that Sowerby himself used reading glasses during a time when he still used the chromatometer (see figure 3.2). The use of glasses therefore does not appear to preclude the use of the chromatometer. In the present experiments, participants with (30%; N=3) and without (70%; N=7) lenses and glasses were included. Based on this limited amount of participants, the use of lenses or glasses does not seem to influence the time needed to learn Sowerby's method, and the distances at which certain colours were reported significantly.[215]

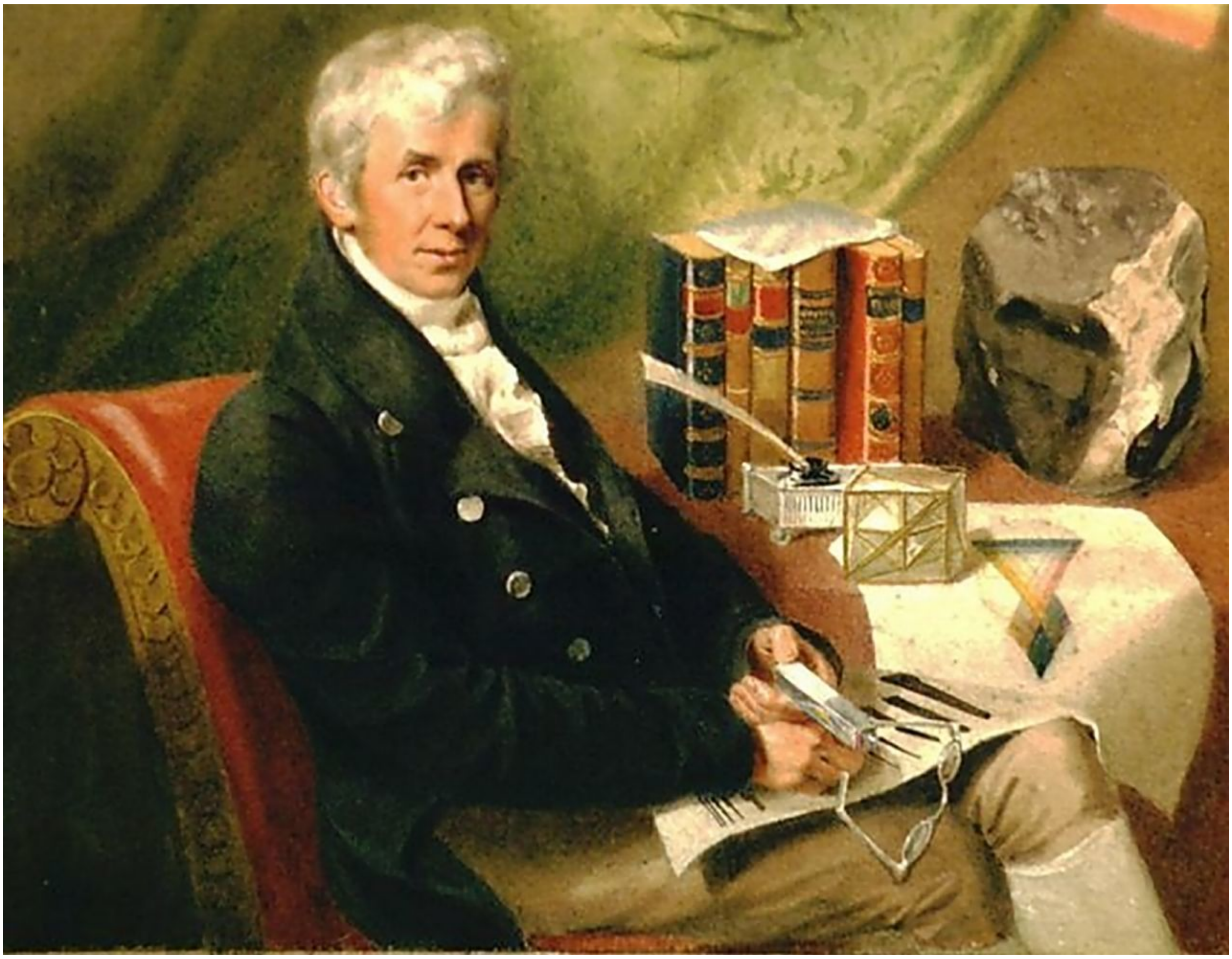

Figure 3.2: Portrait of Sowerby by Thomas Heaphy, commissioned in 1816, displaying him among his "greatest achievements": the Cape of Good Hope meteorite at the right, referring to his expertise in the study of meteors; his most important publications; and his model-box to explain crystallography, under which a colour plate from his *New Elucidations* is laying. At his knee lies the chromatometer and a triangular prism to study it. (Quote: Henderson, p. 283)

[214] Wijk, Helle, et al. "Colour perception among the very elderly related to visual and cognitive function." *Scandinavian Journal of Caring Sciences* 16.1 (2002): 91-102.

[215] However, to be certain of this, a larger study with more participants (at least N = 39) should be conducted.

Materials and environmental conditions
The experiments with participants were performed, in order to investigate if multiple persons using Sowerby's method would all obtain similar results when coding and decoding the same colours. Therefore, the focus of the investigation was on determining whether participant-related factors would influence the obtained results, and it was attempted to keep all non-participant related factors that might influence the perceived colours as constant as possible.

In order to achieve this, all participants executed the experiments on the same time of the day (between 15:30 and 17:00 Amsterdam time). They were tested on an individual basis in separate sessions. All sessions were held in the same room, with the participants sitting at the same desk that was lit by two fluorescent tubes (LUMECO LED T5 PRO 1500 Gen 2+, 34W, 4000K) from above (see figure 3.3). Since the room had no windows, direct sunshine - that might cause differences in light intensity - entering the room was avoided.

All participants used the same prism to generate colours with during all the experiments: a crown glass prism with sides of 30x30x30 cm, angles of 60 degrees and a refractive index of 1.625±0.005.[216] They projected the requested spectra in experiment 1 on the same white wall. The sheet with black patches participants used for experiment 2, and the chromatometer they used for experiments 3, 4 and 5, were all printed with the same printer, a Xerox AltaLink C8055, on the same white paper, with the same black printing ink. The dimensions of the chromatometer and the black patches were all scaled with millimetre accuracy to be identical to the dimensions of these instruments as depicted in Sowerby's *A New Elucidation of Colours*.

For the coding and decoding of colours with Sowerby's method in experiment 4 and 5, all participants used the same objects: pencils from a "Rubye® Professionele 95-Delige Potloden Tekenset". For the coding experiment, the following pencils have been used: Lemon 015 (yellow); Sanguine 006 (red 1); Crimson 058 (red 2); Plum 048 (dark blue) and Light green 010 (green). In the decoding experiment the participants selected a pencil that - according to them - matched the given distances most accurately from this same set of pencils.

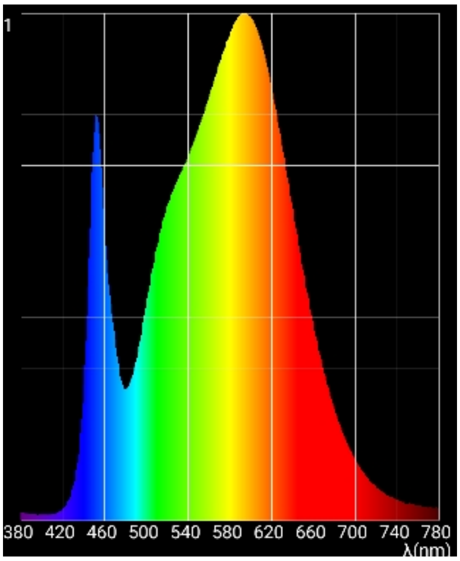

Figure 3.3: a) Spectrum of the LUMECO LED T5 PRO 1500 Gen 2+ fluorescent tubes

b) Impression of the room in which the experiments were conducted, showing one of the fluorescent light tubes at the ceiling, and the opened glass door to the corridor (photo by dr. Hieke Huistra).

[216] I want to thank Rudi Borkus and dr. David Baneke for their help with obtaining this prism and determining its refractive index with a Kern ORA 1GG Analoge refractometer.

Pre-tests and selection of experiments
Before the actual experiments were conducted, three pre-tests have been performed. During the first pre-test, the experiments to be conducted with the participants were selected. During the second pre-test, the colours participants would determine and code were selected. And during the third pre-test, a first run of the experiments was performed, after which the instructions were finalised.

Sowerby describes more than fifteen experiments with prisms in his *A New Elucidation of* Colours. Multiple of these experiments have been conducted with a volunteer during the first pre-test. A selection was made of experiments relevant and required to perform in order to learn Sowerby's method, but that in total would not take more than 1,5 hours to limit the strain put on the participants.

In that way five experiments were selected. The first three experiments were intended to teach the basis of Sowerby's method to participants. Step-by-step, the participants learned how to oriënt the prism to generate colours; what they should look for when generating colours with the prism, and how different thicknesses of black on white paper could generate different tints of colour. At the end of each experiment, the participants were asked to describe as accurately and detailled as possible the colours and tints of colours they had created. Once the participant described the colours and tints as Sowerby intended them to be generated, he/she was allowed to continue with the next experiment.

In the last two experiments, participants were asked to execute Sowerby's method: first to code colours that were selected beforehand into distances on the chromatometer. Thereafter, they were asked to decode distances I had determined beforehand back into perceivable colours.

A schematic outline of the pre-tests and experiments performed during the actual study is presented in figure 3.4. A more detailed description of the experiments, the motivation to select these experiments, and an explanation how Sowerby's method is at some points adapted and extended in order to operationalise it, is presented in the paragraphs after *instructions and language*.

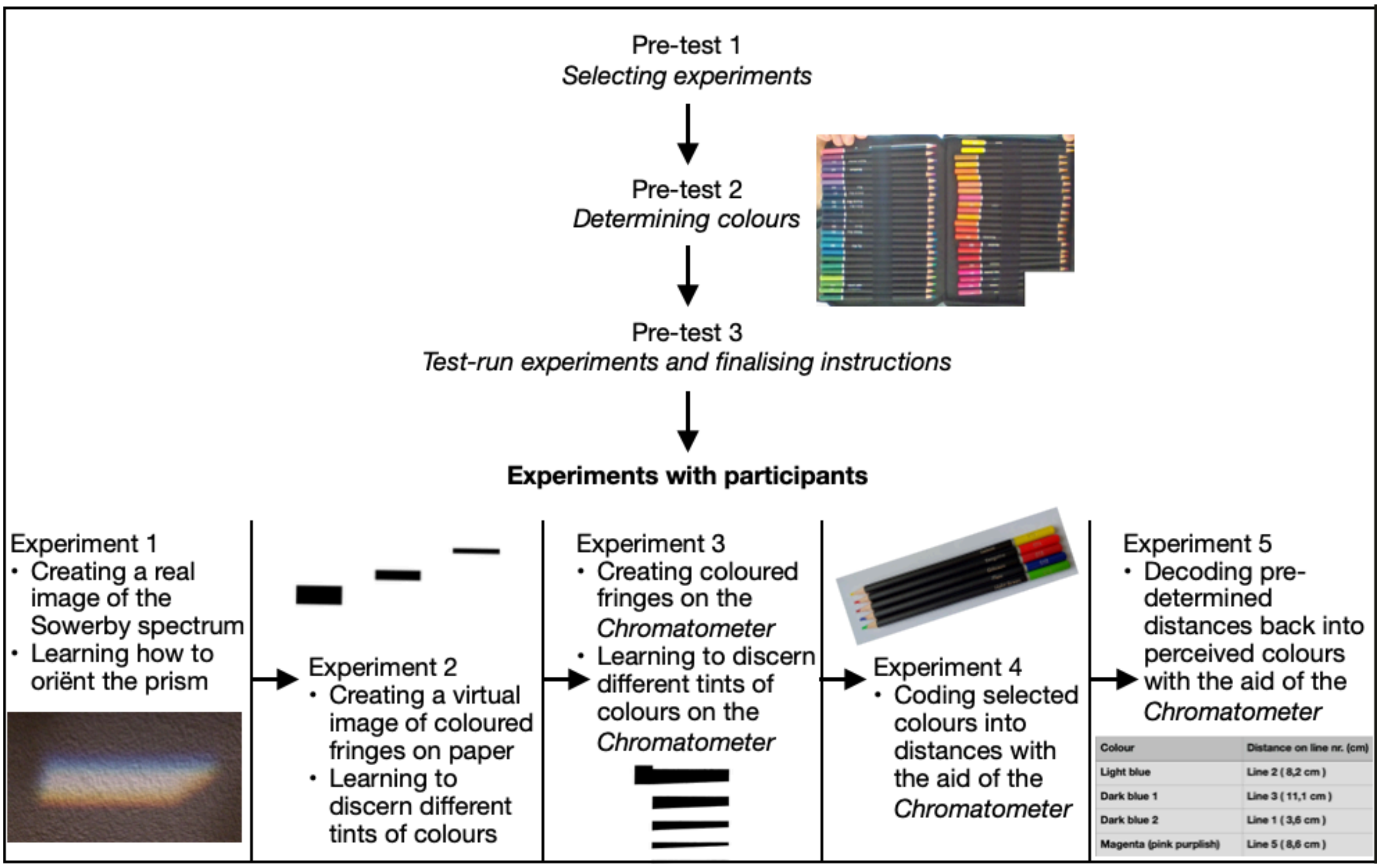

Figure 3.4: schematic diagram of the performed pre-tests and experiments.

Instructions and language
The investigator who conducted the experiments was always one and the same person, who used the same standardised instruction form. Therefore, all participants received the same information with the same amount of detail to learn and conduct the experiments with. The clarity of the written instructions based on Sowerby's descriptions of this experiments was confirmed during a third pre-test. These instructions given to the participants are included in the appendix. Lines written in italics indicate the tips that were only provided when needed for successful completion of the experiment. When this additional information was provided, this was marked by the instructor.

The communication of colours in Sowerby's method is not based on words describing different tints of a colour, but on distances measured on the chromatometer. Nonetheless, it was regarded as valuable to get an indication not only of the end-results of the use of the method, but to follow the intermediate cognitive steps participants went through when learning and using the method as well. Therefore, participants were asked to verbalise their thought process, for which they needed to describe perceived colours as detailed and accurately as possible. Since participants are most eloquent in verbalising perceived colours when describing them in their mother tongue, the sessions have been held in the mother tongue of the participant whenever possible. International students with a mother tongue that the investigator did not speak fluently were allowed to choose if they wanted to receive instructions in English or in Dutch.

Experiment 1
Sowerby intended to "begin in as simple a manner as I could," when it came to explaining his method for generating colours.[217] Therefore, once he asks his reader to take up a prism, he does not immediately ask him/her to look at the chromatometer. Among replicators of prismatic experiments, it is regarded to be less difficult to look at a *real* image created on a wall by projection of light through a prism, in contrast to looking at a *virtual* image perceived by looking through a prism.[218] In the same line of thought, Sowerby first directs his reader to a spectrum created "upon any object within a few inches".[219] When the prism was used in the right manner, this projection would contain a specific ordering of colours: "the middle I call white, as the more direct light, the yellow is below it, the red lowest, and the blue on the uppermost or opposite side."[220] This particular spectrum (see figure 3.5b on the next page) is the base on which Sowerby built his theory and method, and also forms the base of what he intended people to see on his chromatometer. I will therefore refer to it as the "Sowerby spectrum" from here on.

In order to follow a similar didactic structure as Sowerby himself did, it was decided to let the participants of this study start by creating this spectrum as a real image on a wall as well. The first thing one will observe when using the prism, Sowerby describes, is a large white spot, caused by the reflection of the light source by the prism (see figure 3.5a: 1). Therefore, participants were first asked to direct the prism towards the wall, and try to find this white spot. Thereafter, Sowerby describes that a second - but this time coloured - spot could appear in proximity to the first white spot (see figure 3.5a: 2). In his *Elucidation*, Sowerby does not describe explicitly how this second spot could be discovered. Based on my own experience, however, I decided to explain to the participants straight away that they could find this second spot by moving their wrist to turn the prism up and down. Having created this second spot on the wall, participants were asked to describe the colours they perceived in this spot as detailled and accurately as possible. This was done in order to check if participants held the prism "correctly" regarding two factors, and therefore created the above described spectrum Sowerby intended one to see.

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217 Sowerby, p. 8.

218 Nawrath, Dennis. "Die prismatische Farbzerlegung durch Isaac Newton." *Kanonische Experimente der Physik: Fachliche Grundlagen und historischer Kontext.* Berlin, Heidelberg: Springer Berlin Heidelberg, 2022. p. 45; Nawrath, Dennis. "Die Analyse von Newtons Prismenexperimenten zur Untersuchung von Licht und Farben (1672) mit der Methode der Replikation–Ein Erfahrungsbericht." *Experimentelle Wissenschaftsgeschichte*. Brill Fink, 2010, p. 99; Takuwa, Yoshimi. "The historical transformation of Newton's experimentum crucis: Pursuit of the demonstration of color immutability." *Historia Scientiarum* 23 (2013), p. 132.

219 Sowerby, p. 16.

220 Sowerby, p. 16.

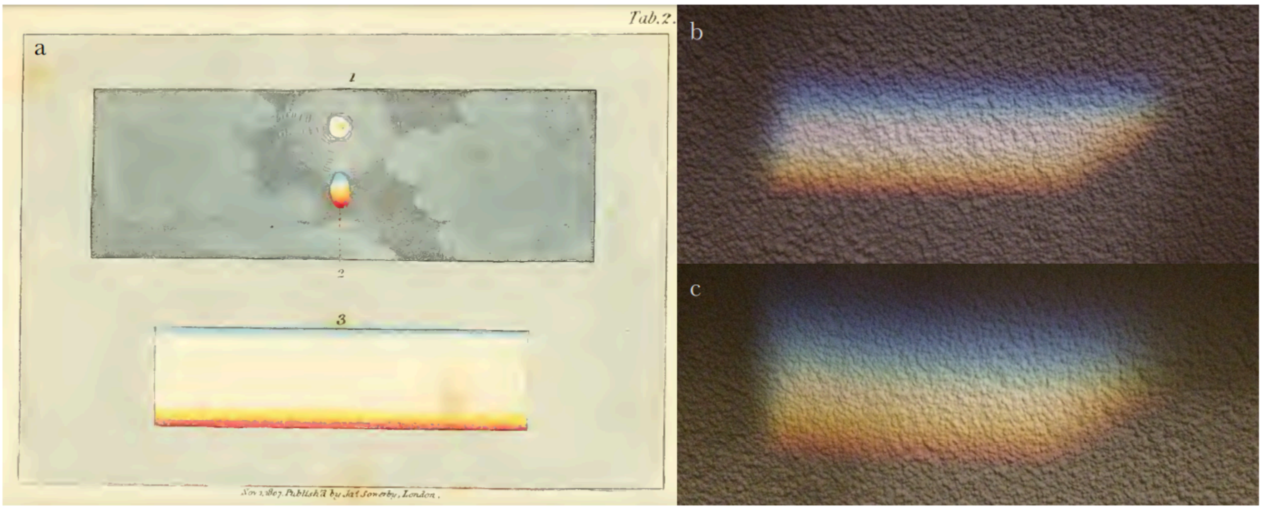

Figure 3.5: a) 1 the white spot one can perceive by looking through a prism. 2. The coloured spot that can appear in its proximity. 3. The “Sowerby spectrum” as depicted on colour tab 2 of *A New Elucidation.* b) The Sowerby spectrum generated on a white wall in dim light. c) the rainbow spectrum generated by turning the prism. (photos by the author).

The first factor, as Sowerby himself describes at length, is the orientation of the prism with respect to the wall. When the base of the prism is held horizontally, and the face of the prism directed perpendiculair to the wall, the Sowerby spectrum is created. However, when the prism is held under a more oblique angle or turned with its tip sideways, the coloured bands of the Sowerby spectrum - that contained only the “primary” colours red, yellow and blue - will start to overlap. In that way they create what Sowerby regards to be secondary colours: orange between the red and yellow band, a green between the blue and yellow band that dispels the white, and “the blue on the darker side is changed into violet and indigo”.[221] During the first pre-test, it was discovered that when the prism was held in such a turned position when one looked at the chromatometer, a participant would also see “secondary colours” being created on this device, which was not what Sowerby intended. Therefore, this first experiment was also used to learn participants to hold the prism as horizontal as possible and under the right angle, so they would also know how to hold the prism when they would start looking at virtual images in experiments 2-5.

The second factor that influences the created spectrum is the distance between the prism and the wall on which the spectrum is created. As was analysed in detail in chapter 1, according to Newton the distance at which the prism is held from the wall makes a crucial difference for the spectrum one perceives: a rainbow when held at some distance, and the Sowerby spectrum when the prism is held close to the wall. Sowerby only mentions in a sub-clause of a sentence that the distance between the prism and the object on which the spectrum is created should be small, without any explanation why this is important. Since it is no part of Sowerby’s instruction, I neither explained to the participants how the distance between prism and wall could influence their observations. However, I regarded it as important that the participants were able to generate the Sowerby spectrum before they proceeded to experiment two, so they would know what kind of virtual image they were expected to generate there. So, if they were unable to generate the Sowerby spectrum because they held the prism too remotely from the wall, I repeated the instruction to move close to the wall.

Once participants had described the right colours that compose the Sowerby spectrum, and no secondary and ternary colours, they were congratulated on successfully completing experiment one, and they were allowed to proceed to experiment two.

Experiment 2

In experiment 2, participants were asked to generate the Sowerby spectrum as a virtual image by looking through the prism at a sheet of white paper with three black patches of different sizes on it (see figure 3.6 on the next page). Sowerby explains that, when one looks through a prism at a

[221] Sowerby, p. 16.

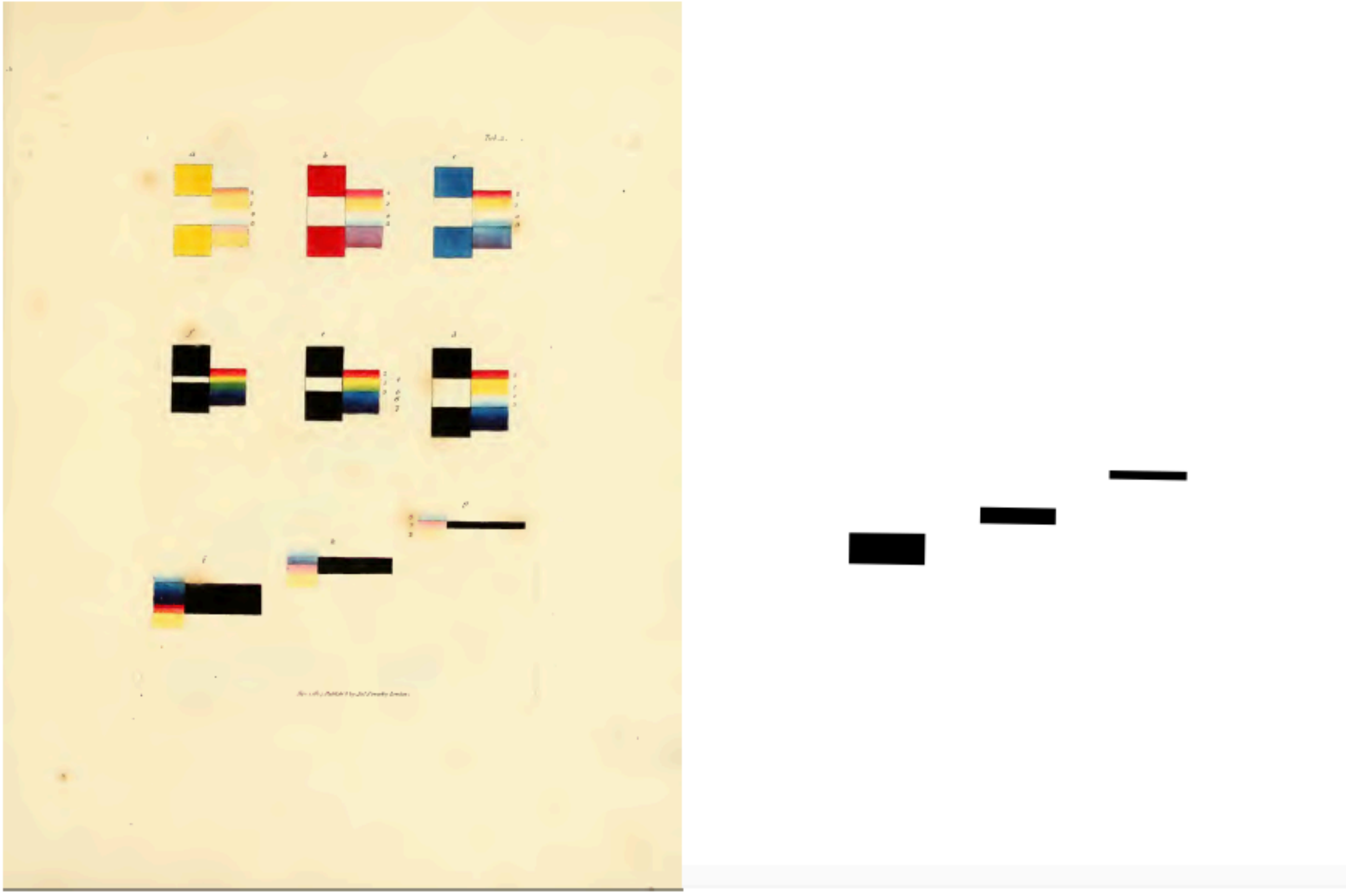

Figure 3.6: a) Sowerby's colour tab 3, with at the bottom (indicated with *g, h, i*) the three black patches used for experiment 2, with left of them an indication of the tints and colours that would be generated on top of the patches when one looks at them through a prism. b) The correctly scaled black patches presented to the participants during the study to generate the coloured fringes.

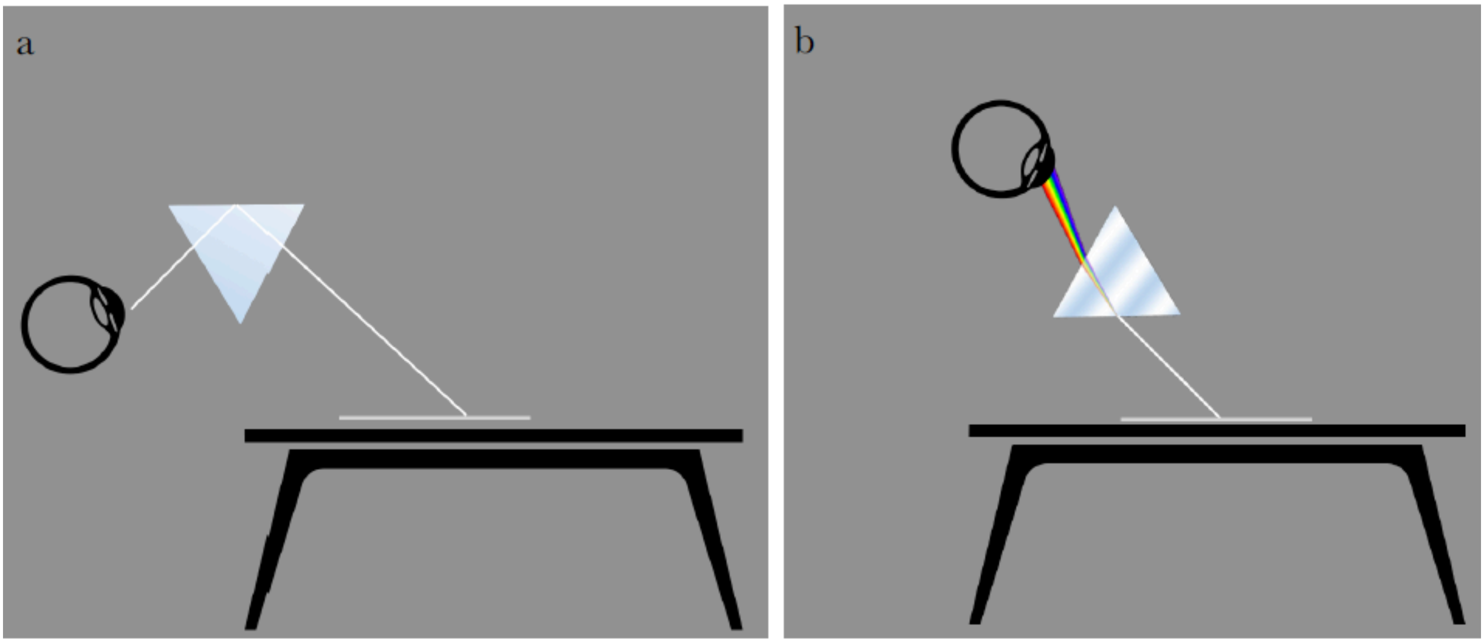

Figure 3.7: a) Orientation of the prism to see a reflection without colours. b) Orientation of the prism to see coloured bands around the chromatometer.

white sheet of paper on which black patches are drawn, coloured fringes will appear at the borders between the black and the white: “a broad light upon black effuses yellow, red and blue, the red and blue always bordering more or less on the black back ground, and the yellow appearing upon some part of the space of light or white.”[222] So, similar, but inverse, to the real image participants had just generated by projecting light through the prism at the wall, they should now - when looking through the prism - be able to perceive a red fringe of colour just below every black patch, and a yellow fringe below those red fringes. At the top of the black patches, they should be able to discern blue fringes. In order to achieve this, they were asked to place the sheet of paper with the black patches on it in front of them on the table, take the prism and hold it close to their eyes in the same orientation they had held it in for experiment one, and look at the sheet of paper through the prism.

Only in the final paragraphs of his explanation of the chromatometer Sowerby himself describes how one should look through the prism: “One angle of the prism should be directed towards it [the paper], and the spectator should look in at the opposite face of the prism towards the lower face, where the spectrum will appear in great beauty and order.”[223] During my own reconstructions of the experiments, this brief explanation turned out to be too concise, and furthermore confusing. For this reason, participants did not receive this explanation immediately, but were first asked to figure out how to look through the prism - instead of along with it at a wall - by themselves. However, it was regarded essential to help participants to find the right orientation during this experiment if they got stuck. Therefore, if needed, tips on how to generate the colours bordering the black patches were provided during the experiment.

Of crucial importance for finding the right orientation is the angle at which the prism is held. As has been explained in experiment 1, on a wall a white spot without colours can be generated, which is a reflection of the light source. Secondly, a coloured spot can be generated, in which the refraction of the light source into its different wavelengths is visible. When looking at the paper, something similar happens: when one turns the tip of the prism directly towards the paper, and looks at the flat face at the opposite side, one will see a reflection of the black patches that does not show any colour (see figure 3.7a). This image is visible upside down since it is mirrored by the prism. However, when the prism is turned so that the flat base of the prism faces the chromatometer, and one looks through a corner downwards, one will see the desired refraction bands appear around the chromatometer at the black-white borders of the patches (see figure 3.7b). Therefore, participants who got stuck were advised to slowly turn the prism between the fingers of one hand until they saw the coloured bands appear. If that turned out to provide too little help, they were advised to look through a small corner of the prism downwards to the paper.

The selected experiments were intended to teach participants sufficiently about Sowerby’s theory to enable them to use the chromatometer themselves to code and decode tints of colours with it in experiment 4 and 5 respectively. According to Sowerby, the black patches are called “productors," since thicker patches would generate more saturated and intense tints of colours on their borders than smaller patches.[224] During pre-test one and two, it became clear that discerning different tints of one colour on the chromatometer itself proved to be difficult: the chromatometer consists of wedges on which the tints of colours become paler in a gradual way that is hard to perceive when one does not know what to look for. Therefore, incorporating an experiment in which participants could learn to discern clearly distinguishable tints of colour was regarded to be an essential step before presenting the chromatometer to the participants: with the three separate patches that have a clear difference in thickness instead of gradually diminishing lines used in this experiment, the volunteers in the pre-tests were able to discern the difference in saturation, intensity and tint of different thicknesses of black more easily.

Therefore, during the experiment itself participants were asked to compare the fringes perceived at the borders of three black patches present on the paper, and indicate which patch generated the most saturated/intense tints of colour, and which one the palest/least intense tints. So, in this experiment participants also learned to couple different thicknesses of the productors to different tints of colour. Once they coupled the most intense tints to the thickest black patch at the left, and the least intense tints to the thinnest black patch at the right, they were allowed to continue to experiment 3.

[222] Sowerby, p. 19.
[223] Sowerby, p. 28.
[224] Sowerby, p. 15-19; 21.

Experiment 3
Experiment 3 was used to see if participants were able to apply the skills they had learned during experiment 2 on the actual chromatometer: perceiving coloured fringes at borders between black patches and the white paper when looking through the prism, and discerning different tints of colour along with diminishing thicknesses of the black productors. Sowerby's chromatometer, however, exploits the possibilities for generating different colours based on black and white contrast on paper in a more advanced way compared to the black patches presented in experiment 2.

Sowerby's chromatometer consists of two distinct parts, here referred to as the upper and the lower part. In the upper part (see figure 3.8), around the productors the colours red, yellow, light blue and dark blue are generated, when one looks at the chromatometer through a prism.

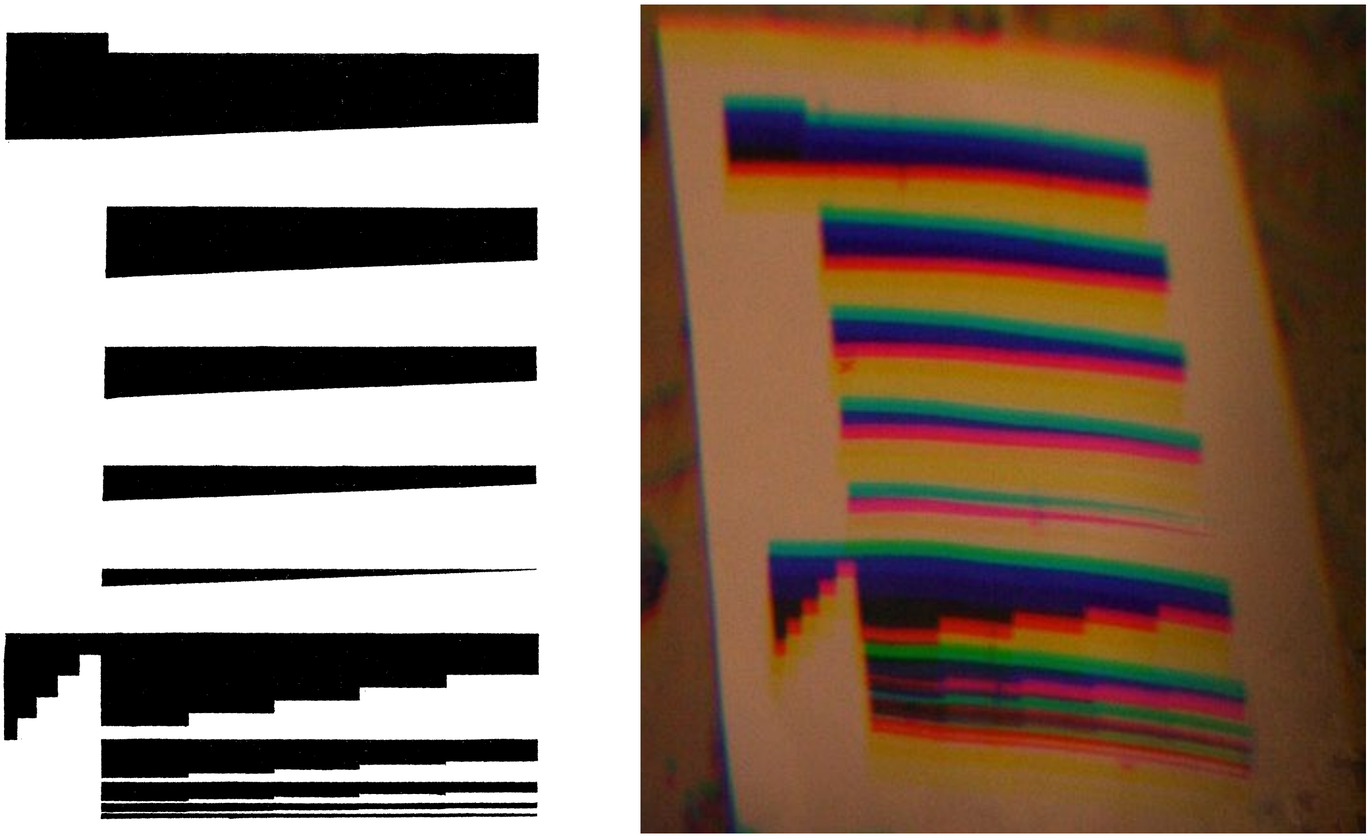

Figure 8: a) Sowerby's chromatometer, with the upper five lines representing the wedged part, and the lower five lines the universal chromatometer or staircase. b) Colours generated on the chromatometer when looking at it through a prism (photo by the author).

These colours, in accord with the colours regarded as *primary* colours by artists and scholars in Sowerby's environment, he regards to be the essential colours from which all other colours can be generated.[225] When the thickness of these productors gradually diminishes from the upper left part to the lowest right part five lines lower, according to Sowerby the intensity of the colours also gradually diminishes:

> We may pass from the upper portion of the wedge to the next, beginning immediately where the above left off, and consequently with the same tint, (which may be noted as a proof of the proper position of the prism it is viewed by,) this will become more and more dilute to the end. The third part of the wedge begins where the second left off, with the same proportion and colour, and so of the other two as these diminish, the red diminishes, or becomes more and more dilute, till lost at the end of the fifth or last line of the wedge.[226]

[225] Sowerby, p. 6
[226] Sowerby, p. 26-27.

At the lowest of the five lines, the blue and red start to overlap, by which the red at the far right is completely covered by the blue and forms the secondary colour magenta.

The lower part of the chromatometer (see figure 3.8), also called the “staircase” or “universal chromatometer," is especially designed to generate the secondary and tertiary colours. Since the lines are placed very closely together, the primary colours yellow and blue overlap to a large extent, thereby creating the secondary colour green. On very close inspection, according to Sowerby also ternary hues of brown can be generated in this part of the chromatometer.

In experiment three, participants were asked to look at the chromatometer through the prism, and indicate if they could see the same coloured fringes bordering the black patches as they had seen during experiment 2. Once they confirmed that they were able to see red, yellow and blue fringes around the top part of the chromatometer, they received the explanation that “because the coloured stripes are clearly distinguishable, Sowerby says the vertical height is of no importance. If someone says “red”, everyone would know at which stripe one should look.” However, participants were made aware that the diminishing thickness of the black patches from left to right would influence the perceived intensity of these coloured bands, and that moving from the highest patch to the ones below this change in intensity would continue. Therefore, it was indicated that “the horizontal distance is crucial according to Sowerby, because this distance determines the tint and shade of the colour one wants to describe.”

Thereafter, participants were asked to focus on the upper part of the chromatometer (the five wedge-shaped lines at the top). They were allowed some time to look attentively at these lines, after which they were asked to indicate if they could perceive “differences in the tint and shade of the colours between the broadest part of the chromatometer at the upper left, and the smallest part at the bottom right.” Once they correctly indicated that the upper left wedge of the chromatometer generated the most intense coloured fringes, and the bottom right wedge produced the palest coloured fringes, in which the red had fully disappeared and a magenta colour had taken its place, they were allowed to continue with experiment 4.

Selection of colours
In his book, Sowerby explains how his method works. However, he himself does not present his reader with material that could be used to practice his method with; he does not describe specific objects or colours, with an accompanying answer sheet of the correct distances on the chromatometer correlating with them. This is not surprising, since Sowerby did not trust the objects or pigments of his day as faithful carriers to disseminate information about colours. He began to develop his colour standardisation theory exactly for the reason that the colours around him appeared to fade, and colours on paper for the practice of an experiment would undergo the same fate. So, if I wanted to test if his method worked, I would need to make a selection of objects that would provide a stable colour reference during the entire run of the study. These I could present to all of the participants in order to see if they would score them the same way, as is aimed for in his method. To operationalise this, I decided to present participants with coloured pencils with standardised names and codes for easy reference, taken from a “Rubye® Professionele 95-Delige Potloden Tekenset” (see figure 3.9).

Figure 3.9: The Rubye® Professionele 95-Delige Potloden Tekenset (photo by dr. David Baneke).

During the second pre-test, I determined the colours that would be used for experiment 4 and 5. In order to limit the exertion asked from the participants, it was decided to limit the number of colours used in the fourth experiment to four primary colours and one secondary colour (according to Sowerby's classification), and to select three primary colours and one secondary colour for the fifth experiment.

During experiment 4, the coding experiment, participants would be presented with a coloured pencil, asked to mark the position at which they perceived this colour on the chromatometer itself, and thereafter measure the distance at which they had placed their mark on one of the lines of the chromatometer in cm. For this experiment pencils with the following colours were selected: Lemon 015 (yellow); Sanguine 006 (red 1); Crimson 058 (red 2); Plum 048 (dark blue) and Light green 010 (green) (see figure 3.10). Yellow, red and dark blue were chosen in order to see if participants would select the same position on the chromatometer as the exact spot where these primary colours and their tints were generated. A second red with a more orange hue was selected, in order to see if participants would be able to distinguish different hues of this colour, by placing the crosses indicating these hues at distinct places, and if these distinct places would be consistently chosen among participants. Light green was selected in order to see if participants were able to generate secondary colours in the lower part of the chromatometer, and if so, if they would discern this specific tint of green at a similar place.

Figure 3.10: The selected pencils participants used during experiment 4 (photo by dr. David Baneke).

During pre-test two I determined, for the decoding experiment, four distances at the chromatometer at which a specific tint of a colour was visible based on a light blue, two dark blue and a magenta object. Since Sowerby's method was intended to foster universal communication about colours between savants and artists at remote locations and times, using their own prisms and chromatometers, the determination of these distances was executed not in the test-room of the experiment, but at a different location with a different lightening condition, using a different prism.

During this fifth experiment, I would ask the participants to select a pencil from the "Rubye® Professionele 95-Delige Potloden Tekenset" that matched the tint discerned at this specific location the clearest. But since the objects used to determine the distances were not identical to the pencils present in the set, I, as the investigator, would be unable to influence the participants in selecting the "right" pencil from the set, since I neither knew what pencil resembled the tint present at the determined positions best in the perception of the participants under their specific testing conditions.

A certain light blue colour, with a distance of 8.2 cm on line two of the upper part of the chromatometer, was chosen. Also two dark blues, with distances of 3,6 cm on line 1, and 11,1 cm on line 3 were selected. In accord with Sowerby's theory it was expected that, since these positions lay 35,3 cm apart on a chromatometer that was in total 65 cm long, participants would select different pencils for these different tints of dark blue. Lastly, magenta at 8,6 cm on line 5 was selected in order to see if participants would be able to distinguish the secondary colour created at this line, since the red and blue fringes would merge on this line, and if they would perceive this secondary colour in a similar way.

Experiment 4
Before the start of the fourth experiment, it was explained to the participants that after completing experiment 3, they had finished the short learning trajectory needed to enable them to use Sowerby's method themselves. Now, I would first ask them to translate 5 colours into distances

with his method during the fourth experiment. Thereafter, during experiment 5, I would ask them to decode 4 distances I determined in advance of this study back into perceivable colours. Furthermore, it was explained to them that the fourth experiment, the coding experiment, would consist of two parts: “firstly, placing crosses on the chromatometer itself, and secondly determining distances on the chromatometer.”

The participants were asked to take, one after the other, the selected pencils “Lemon 015” (yellow), “Sanguine 006” (red 1), “Crimson 058” (red 2), “Plum 048” (dark blue) en “Light green 010” (green) out of the pencil case. They were reminded that during experiment 3, they had been able to see coloured fringes of diminishing intensity on the chromatometer when they looked at it through the prism. Now, they were asked to look attentively at the colours present at the back of these pencils.[227] Once participants had a clear conception of the colour present at the back of the pencil, they were asked to take up the prism again, look through it at the chromatometer, and place a cross on the chromatometer at the exact spot on which they saw this perceived colour and shade the clearest.

Participants did not receive an explanation that the secondary colour green could be perceived in the universal chromatometer at the bottom of the sheet immediately. As is described in more detail in the results section, this was unnecessary for most of the participants, since they had already discovered the presence of green in the universal chromatometer themselves at this point. However, if a participant had not yet discovered where the secondary colour green could be found, he or she would be made attentive to the colours generated in the universal chromatometer.

At this point, it was repeated that the diminishing thickness of the lines on Sowerby’s chromatometer causes the diminishing of the intensity of the colours along the horizontal axis. In that way, the participants were made aware that if one wanted to communicate which intensity of colour a certain object had to a correspondent, it was this horizontal distance that should be communicated. Furthermore, it was explained that the name of a colour, for instance “yellow” would be sufficient for a correspondent to know in which of the coloured fringes he or she should look at the vertical axis, when receiving a description of the colour a certain object possessed. It was thus explained to the participants that the vertical height above or below the chromatometer at which they had placed their marks was, according to Sowerby, unimportant. Therefore, the participants were asked to only measure the horizontal distance at which they had placed their crosses on the chromatometer with a ruler, and note this value down in cm with one decimal precision on a notation sheet.

The chromatometer presents multiple lines below each other. If the length of the paper would have allowed it, each would be part of a long black line of gradually diminishing thickness. However, since a paper sheet has a limited length in the horizontal direction, Sowerby decided to cut this long line into five parts, and place them below each other. The thickness at the end of the first line is thus identical to the left part of the second line, and the thickness of the left part of the third line is identical to the thickness of the right part of the second line, etc (see figure 3.8). Therefore, the horizontal distance at which a certain tint is present, should be measured as the length of the continuing line. For example, to determine a distance for a cross at the third line, one should start measuring the length of the entire first line, the entire second line, and the distance from left to right until the point where the cross was placed on the third line. However, it was decided to spare the participants from this time-consuming arithmetic exercise. Instead, they were asked to note down the number of the line at which they had placed their crosses for each colour on the notation sheet, and to only measure the horizontal distance at this specific line. After completion of the experiments, I myself did the math in order to obtain the distance as if the chromatometer had been a continuum.

In order to differentiate between crosses placed at the upper part and lower part of the chromatometer, participants were asked to write the word “staircase” on the notation sheet, when they had measured a distance in the universal chromatometer.

Once participants had noted down all the numbers of the lines at which they had placed their crosses, and the horizontal distances measured at these lines, they were allowed to proceed to experiment 5.

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[227] Since the colours present at the tips of the pencils in some cases were different from the colours at the backs, it was stressed that they should only look at the colours at the back of the pencils.

Experiment 5
In experiment 4, participants translated perceived colours into colour names and distances. This is according to Sowerby the necessary information to communicate towards others. However, the second half of his method requires people to translate this coded information back into a perceivable colour. Whether this indeed works was tested during the fifth and last experiment, the decoding experiment.

When a correspondent, according to Sowerby's method, received a name of a colour and a distance expressing its saturation, all he or she needed to do was take a prism and a chromatometer, measure the reported distance at the chromatometer, and look through the prism at the described coloured fringe at this distance. In that way, a person would be able to perceive exactly the same colour that someone else had conveyed to him/her.

However, in order to be able to find a way to measure if this method indeed works and if it leads to standardised results, just looking through the prism could not be the final step of the decoding experiment; since I would not be able to look through the eyes of the participants and see exactly what colour they would see myself. Asking for photographs would introduce problems regarding colour standardisation of pictures, and would not show the perception of a tint of colour of the participant, but only the colour captured by the camera. Therefore, it was decided to present a range of tints of colours to the participants, again by making use of the "Rubye® Professionele 95-Delige Potloden Tekenset," and allow them to select the pencil that resembled their perception of the presented colour the closest. Although this pencil set contains a broad range of tints for most colours, it might of course be possible that the exact tint perceived by participants was not present in the case. However, it was expected that participants in that case would select the pencil resembling the perceived tint the closest, and therefore that this operationalisation of Sowerby's method would enable to investigate if it would provide standardised results. With standardised results, two outcomes would be likely. The first possibility would be that everyone would perceive the same colour at the given distance, and that matched one pencil exactly. Therefore, all participants would select the same pencil from the set. The second possibility would be that none of the pencils matched the tint of the colour perceived at this distance exactly, but it lay in between the tints of two coloured pencils participants could select. In the second case, two pencils might be selected by participants.

During the experiment itself, I provided the participants with the names of the four colours, light blue, two dark blues, and magenta, accompanied by a distance to indicate their tint I had determined in advance of the study. First, the participants were asked to measure the distance provided for each colour on the chromatometer, and place a line there in order to be able to easily find these positions back when they would look at them through the prism in a later step. During pre-test three, it was discovered that placing a long vertical line that extended above and below the black patch at the given distance on the chromatometer provided the easiest reference for further steps. Although Sowerby does not provide a procedure for the decoding part of his method, it was regarded important for successful completion of this experiment to assist the participants by giving them this suggestion.

Once participants had placed their marks on the chromatometer, they were asked to take up the prism again, and look through it at the vertical line they had drawn for the colour light blue. They were asked to study the perceived shade of light blue at this distance attentively, and thereafter select the pencil from the pencil case that resembled its hue and shade the closest. This procedure was repeated for each of the other colours.

In case a participant saw multiple pencils that might match the perceived colour and tint, I asked them to select the one matching it the closest and note its name in the box on the notation sheet. However, I allowed them to list the other pencil(s) behind the box, and asked them to explain why they made this choice.

After selecting one or more pencils for each colour and noting them down, participants had completed the fifth experiment, and in consequence the entire session.

Results and analysis

The two central questions in this study, are: to what extent is Sowerby's method teachable to participants in a limited amount of time (1,5 hours)? And to what extent does Sowerby's method generate standardised results? In this section, I shall describe the performance of the participants, answers to the posed questions of the instructor, and their remarks upon Sowerby's method, in order to answer these research questions.

Regarding experiment 1 and 2, the "learnability" of the experiments will be analysed by means of the average time participants needed to complete experiments successfully; a description of the difficulties participants encountered when trying to complete their tasks; a description of the assistance of the instructor participants needed to overcome these difficulties, and an indication of the extent to which participants were able to complete experiments successfully. Experiments 3 and 4 also generated valuable information about the learning process of the participants, which will be described. Furthermore, the descriptions of the perceived colours and tints in experiment 3, will provide information on the extent to which participants perception of colours and tints on the chromatometer is similar. In experiment 4 and 5, numerical information based on the execution of Sowerby's method by participants will be presented and analysed, which also provides insight into the extent to which Sowerby's method leads to standardised results.

Experiment 1

After receiving the instruction to move with the prism towards the white wall behind her and trying to project a white spot onto it, one participant immediately verbalised her understanding that this white spot was caused by a reflection of the fluorescent tubes hanging at the ceiling. Since the room in which the experiment was held was lit by two instead of one light source(s), three participants at first remarked to see a second spot without colours, since they were able to project a reflection for both of the fluorescent tubes on the wall instead of the refracted spectrum of colours that according to Sowerby would accompany the white reflection of just one light source.

Two participants needed a repeated explanation on how to hold the prism, since they held it vertically instead of horizontally. The instruction to move one's wrist up and down in order to find the second, coloured spot on the wall, only needed to be repeated for one participant. In order to find this second coloured spot, however, 70% of the participants needed to move closer to the wall than they initially intended to, which indicates that a lack of explanation about the importance to hold the prism very close to the wall leaves participants unaware of its necessity to successfully complete the experiment.

Four participants were able to generate the "Sowerby spectrum" immediately once they perceived the coloured spot on the wall. One of them did not even need to be led through the steps of first generating the white spot on the wall, and thereafter starting to search for the coloured second spot, but reported the right colours of the Sowerby spectrum immediately when directing the prism to the wall, and therefore finished the experiment in less than two minutes.

One of the participants was immediately able to perceive red and yellow above the white center of the spot, but was at first unable to generate the blue(s) at the bottom of the spot as well. Turning the prism around the horizontal axis caused the blues at the bottom to appear as well. Two participants, on the other hand, generated a spectrum that included the colours Sowerby intended one to see, but multiple times above each other. One of the participants reported to perceive a second yellow below the blue band, while the other participant reported a second purplish blue above the red band. In both cases, turning the prism proved to remove these deviations in regard to the intended spectrum.

Three of the participants first reported to see a spectrum containing a green colour in the middle. For one of them, moving the prism closer to the wall was enough to remove the green colour at the center. For the other two participants, it was also needed to instruct them to hold the prism more horizontally before the green in the center was removed.

On average, participants were able to perceive and describe the colours of the Sowerby spectrum on the wall after 3:26 minutes.

Experiment 2

Experiment 2 proved to be a bigger challenge for most of the participants. Switching from analysing a real image projected on a wall to a virtual image proved to be difficult for many of them. On average, it took participants more than twice as long to complete this experiment compared to the previous one (average time needed: 7:25 minutes). One participant indicated to have difficulties seeing any object through the prism, because she saw a reflection of the lights at the ceiling instead. 70% of the participants indicated at their first try that they were able to see the black patches through the prism, but that they did not see coloured fringes around them. Most likely, they saw a reflection of the patches through the prism. Two participants remarked that they were able to see the black patches in their field of view, but they could only see coloured fringes around other objects in the room. Once these other objects were removed from their field of view, they were able to see the fringes around the black patches. Also, some participants ($N = 6$) reported to be able to see coloured fringes, but not around the black patches. One participant remarked to see faint colours around the black patches, but that these colours were much more vivid at other places on the paper. Other participants reported to perceive “undulations of colour” in continuous lines along the patches, or other arch-like shapes instead of straight lines ($N = 3$). One of them described it, while making wave shaped movements with the arm that was not holding the prism, in the following manner: “There are different kinds of undulations, so, it is like a hill and valley sort of situation with the biggest sort of peak intersecting with the thickest band, which is also darkest there.” What most likely happened in these cases, is that the participants were looking at a reflection of the patches. On top of this reflection, coloured bands caused by refraction of other dark-light interfaces around objects in the room can be projected. These coloured bands can be moved over the visible black patches when turning the prism, since they enter the eye of the observer via another route. The perceived undulations are most likely coloured stripes generated at the border of the table at which the participants performed the experiment. Since the black patches were presented not at a straight line but with a difference in height besides each other, participants might have had the tendency to hold the prism under a slight angle to get all three patches at one line in ones field of view. In this way, the prism would be held at an angle with regard to the border of the table, which would therefore look as if it was bent slightly.

When the instructions were extended with additional tips on how to use the prism in the way Sowerby intended, most participants in the end succeeded to generate coloured fringes in the right colours, with the right shape, and at the right orientation in regard to the black patches. From the five tips that could be provided for this experiment (closing one eye; holding the prism closer to one’s eye; holding the prism between the fingers of one hand; looking only through the front edge of the prism; slowly turning the prism until colours became visible), all participants needed at least one tip to achieve the intended spectrum around the black patches. The tip to hold the prism closer to one’s eye was in two cases given multiple times to one participant. On average, participants needed three tips in order to see the right spectrum, but the amount ranged from 1 to 6 tips.

Only one participant proved to be unable to generate the right spectrum of colours within 15 minutes, despite being given all the tips. In order to keep the entire session within the set timeframe, it was decided to move forward to experiment 3 after 15 minutes. Once this participant replaced the sheet with black patches with the chromatometer itself, he proved to be able immediately to describe the right colours at the right positions. Experiment 2 therefore turned out to be confusing rather than a helpful intermediate step in his learning process.

From the participants who were able to successfully generate the colours around the black patches, seven out of nine were able to discern that the thickest black patch generated the most intense and saturated tints, the thinnest the least intense and saturated tints, and the middle one intermediate intense and saturated tints. One participant indicated to see no difference in tint between the patches, and two participants indicated that the thinnest black patch generated the clearest colours and the thickest the palest.

Experiment 3

After completion of experiment 2, all participants were almost immediately able to generate coloured fringes around the black lines when presented with the chromatometer. Two participants instantly remarked that they could perceive more colours on the chromatometer compared to the three black patches: a purple and green were present as well. One of them described this as follows: “I do not know if this is going to be your question, but in the part with the staircase, so, the lowest part of the sheet, there I can very clearly see a green.”[228]

The average time needed to follow all the steps and to answer the questions was a little more than half the average time participants had needed in the former experiment to answer the same questions about colour and saturation: 4:29 minutes. Therefore, it appears that participants had learned some basic skills regarding the use of the prism and the colours that were intended to be generated during experiment 2, which enabled them to perform similar actions for this new ordering of black patches a lot faster.

When asked if participants could perceive differences in saturation or intensity of colours between the thickest part of the chromatometer at the upper left, and the smallest wedged part at the lower right, all of them answered in the affirmative. All participants perceived the colours at the upper left as being a lot darker and more intense, while the colours at the lower right were very

[228] All English quotes have been transcribed literally. I translated all Dutch quotes from participants into English.

pale or faint. Two participants even indicated that at the lower right of the wedged part, all colours as well as the black line disappeared when looking through the prism, and only a white remained visible. However, when questioned in more detail, 50% of the participants indicated that while the differences in saturation between these extremities of the chromatometer were clearly visible, they discerned no differences in saturation at the two or three thickest lines at the top. Only at the two lowest lines, they could clearly see differences in intensity between the lines.

There also proved to be differences between the extent to which participants perceived differences in saturation on the lines: four participants indicated to see a clear diminishing of saturation from left to right, while one participant indicated to find it very difficult to see some difference: "I found it very, very hard to discern a difference between tints, you know, from left to right."

All participants indicated to see differences in saturation for all colours. One participant indicated that the difference in tonality was larger for the blue fringes compared to the yellow fringes, while another participant indicated to see the largest differences for the yellow compared to the blue. Participants unanimously indicated that the red perceivable at the highest wedges vanished, and that instead at the lowest wedges a magenta (pink purplish) colour appeared. Two participants correctly described that this was due to the overlapping of the red and blue fringes once the black patches became smaller. However, the exact position at which participants indicated the transition point between red and magenta varied greatly: one participant indicated that she could only perceive red at the highest line of the chromatometer, all others presenting shades of pink and purple, while most other participants only indicated the generation of pink or purple midway the chromatometer (N = 7), or even only at the last line (N = 2).

Experiment 4

During experiment four, participants were asked to place a cross at the exact location where they discerned the colour and tint of the pencils Lemon 015 (yellow); Sanguine 006 (red 1); Crimson 058 (red 2); Plum 048 (dark blue) and Light green 010 (green) the clearest. Eight out of ten participants indicated that they did not discern at least one of the presented colours at one single position on the chromatometer, but that this tint was present at multiple places. To give some examples:

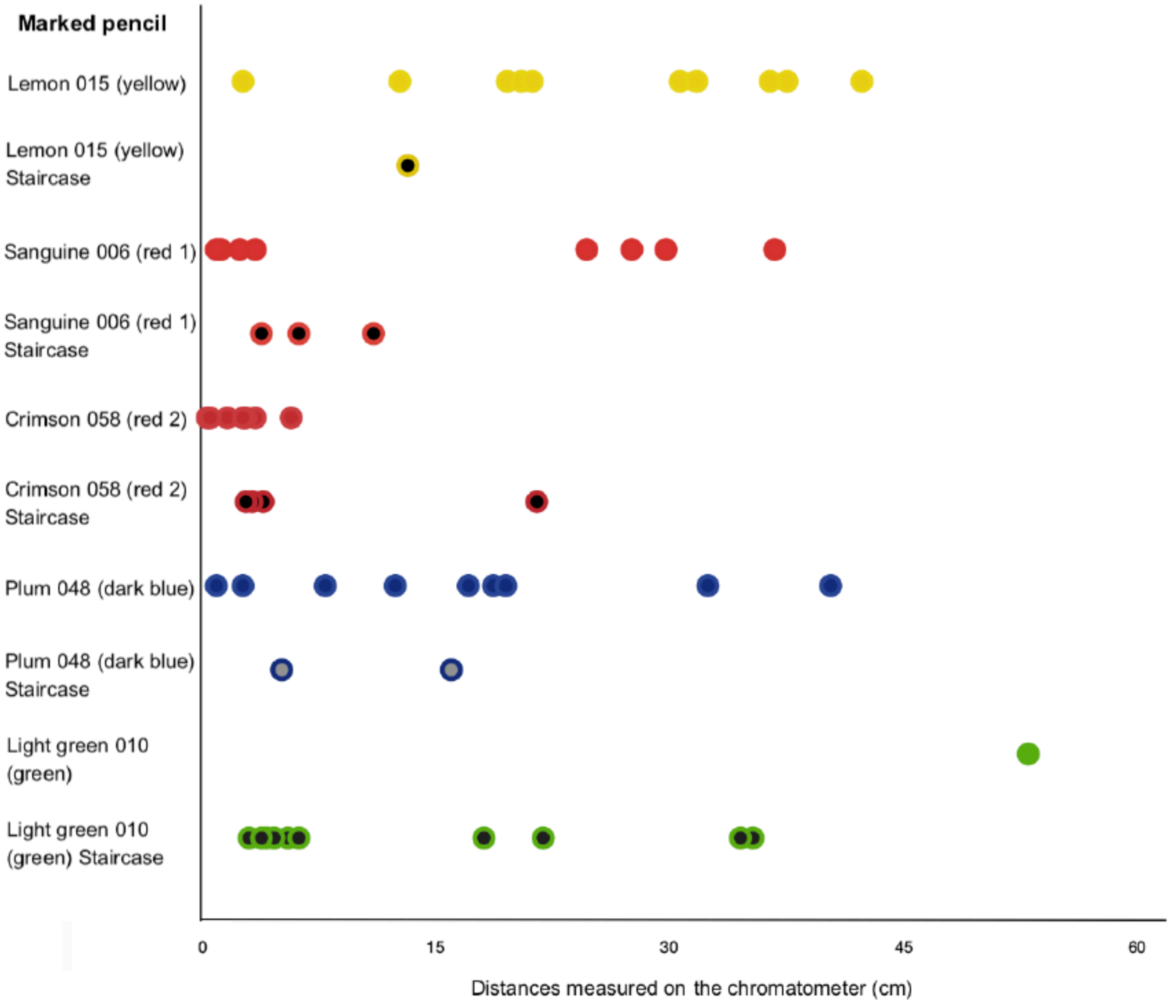
> For that yellow one, the cross that I placed for that one, well, I could have extended that to make a very long line. I saw that yellow colour everywhere. It's so difficult to make choices.
>
> There are several stripes that are yellowish in colour, do I place a cross on all of these stripes?
>
> There are so many shades of yellow. It gives me the impression that I'm just guessing a bit. It's very difficult because there is very little difference between the different lines, so I'm just choosing one at random.

Specifically, six participants expressed this remark for the pencil Lemon 015 (yellow); two for Sanguine 006 (red 1); two for Crimson 058 (red 2), one for Plum 048 (dark blue), and two for Light green 010 (green). One of the participants even started noting the ranges in which he discerned the same tint of the indicated colours on the chromatometer, instead of placing one single cross at an exact distance.

Keeping these remarks in mind, the investigator nonetheless stressed that only one single cross was allowed to be placed on the chromatometer - since that is how Sowerby's method was intended to function - and asked to carefully select the exact spot at which the requested colour and tint of this colour was visible the clearest.

In diagram 1 (on the next page), the horizontal distances are plotted at which participants placed their crosses. If Sowerby's method indeed would generate standardised results, one would expect to see that for each colour a single position was marked by all participants as the location where this colour was present. Inspecting the diagram, however, one can immediately see that for most colours this is not the case. For 4 out of 5 colours, the crosses are placed over a span of 40 cm of the chromatometer. Since the chromatometer is no more than 64.9 cm long in total, the crosses cover 60% of its entire width instead of being all at approximately the same place.

Diagram 1: Distances marked by the participants to be matching the colour and tint of the presented pencils the closest.



With respect to the distinction of the wedged-chromatometer and universal chromatometer, there was a wide divergence, too. For each colour, some crosses were placed in the upper part of the chromatometer, but some participants decided to place crosses for the primary colours in the universal chromatometer:

> I can see the red very clearly in the lower part with the staircase. But when I turn the prism more, so when I turn the lowest corner further away from me, than I can see it also in the upper one. But I see it a lot more clearly in the lower one.

One of the participants indicated that the stepwise divisions in the universal chromatometer made the generated tints better distinguishable from each other, and therefore indicated a preference to mark the primary colours in this lower part: “the same implies for the colour yellow, it is a lot easier to place that one in the staircase.”

With regard to the learnability of Sowerby’s method, participants proved to be able to figure out parts of Sowerby’s theory that I had not explained (yet) to them. As has been described above, for experiment 3 participants were asked to focus on the upper part of the chromatometer - where the primary colours are generated. However, some participants (*N* = 3) already remarked during this experiment that they perceived green (and sometimes other secondary colours) in the universal chromatometer at the bottom of the sheet. 60% of the participants already remarked that the colour green was present in the universal chromatometer before they had to mark a cross for the green pencil in experiment 4, and needed no further instruction on the generation of secondary colours in order to successfully complete this experiment.

Two participants were able to generate a green colour in the wedged part of the chromatometer as well. One of them indicated that when he looked at the prism from a very oblique angle, very faintly a bit of green appeared "in the horizon". Once this participant discovered the green fringes in the universal chromatometer, however, he remarked that he found the green in this bottom part "a lot more convincing," and therefore decided to replace his initial cross for green in the wedged part of the chromatometer by a cross in the universal chromatometer. Only one participant did not discover the green in the universal chromatometer during the session, and therefore placed the cross in the wedged part.

Only Crimson 58 (red 2) was placed in a relatively standardised position: almost all participants placed this colour at the beginning of the upper chromatometer (M: 2,5; SD: 1,9). Sowerby himself also describes where he intends to generate a crimson colour in his chromatometer:

> As an inch and 1/4th [of black on white paper; in height] produces scarlet, when viewed at a foot or more, one inch produces red and 4/5ths produce lighter red approaching crimson.[229]

Although Sowerby here does not measure the horizontal distance, but the vertical thickness of the productors, this can be translated into a horizontal distance, which would be ±5 cm on a chromatometer with the correct scale (as used for this study). The mean distance for crimson reported in this study was 2,5 cm instead of 5 cm. Therefore, Sowerby might have used an object with a different hue that he called "crimson" for his description, or environmental or material factors might have caused a divergence.

One of the participants remarked that the pencil "Crimson 058" looked very brownish to him. In Sowerby's eyes crimson is a primary red colour, and it does not contain a tertiary brownish component. However, it was very interesting to see that this participant entirely on his own unraveled how to generate tertiary colours in the universal chromatometer, and where a brownish red was positioned: "When I zoom in on that red edge [jn the staircase] to a large extent, in that way it appears that some red merges with the black, creating a sort of brownish red."

Experiment 5

During the fifth experiment, participants were asked to select a pencil from the pencil case that resembled the colour and tint perceived at a given distance the closest.

The first colour examined was light blue at a distance of 8,2 cm on the second line (23,5 cm on a continuous chromatometer). In the pencil case, there were approximately four pencils present with a light blue colour. As has been explained above, if Sowerby's method leads to standardised results, two outcomes would be likely: either, everyone would perceive the same colour at this distance, exactly matching one pencil. All participants would in that case select the same pencil from the set. If none of the pencils precisely matched the tint of light blue perceived at this distance, but if the colour lay in between the tints of two light blue pencils participants could select, two pencils might be selected among the participants. Diagram 2 shows that instead of these possibilities, three different pencils were selected (see also figure 3.11). The most frequently chosen pencil (N = 5) was Sky blue 065, but the pencil ultramarine 019 (N = 3) which is slightly darker in tint, and the pencil Turkish blue 059 (N = 2), which is a more greenish blue, were also selected by some participants.

Participants had been asked to decode two distances on the chromatometer for the colour dark blue: one on line 1, and one on line 3. For both dark blues, Plum 048 was selected most frequently as the best resembling pencil (see diagram 3 and 4 below). Three participants chose Plum 048 as the pencil resembling the perceived colour best at both distances on the chromatometer. However, if the chromatometer indeed showed different tints at different distances, one would have expected to see two different pencils being chosen for these varying tints. One of the participants remarked about the second dark blue she needed to choose a pencil for: "This one is complicated. It seems to me the same as the previous dark blue. It is hard to determine what is right, but I think I'll go for the same one. It's just I think it's quite purple." And another participant had in mind that, according to the theory, the same pencil should not be selected twice. However, this participant criticised the limited amount of purplish pencils present,

[229] Sowerby, p. 26.

and found it important to select a pencil that encompassed the purplish hue accompanying the dark blue colour he saw on the chromatometer at this distance:

> Participant: Yes, of course it is now the challenge not to select Plum again.
> Instructor: If you think that the best match for this distance is Plum, you should choose Plum. If you think that another pencil matches better, you should select that other pencil.
> Participant: I'll do my best, but there are not too many purplish pencils. So, I think that Plum is the best one again.

Furthermore, multiple participants remarked that their choice for the dark blue pencils was influenced because they had already scored a dark blue pencil, Plum 048, during experiment four:

> We did use Plum just yet, didn't we? Well, now, all right, I want Plum 048.

> Well, the thing is, I actually think that this dark blue [the second one] is a bit purplish. But I neither think that the purple pencils are a good match. I don't really know what to choose. I see very little difference between the right and left side of the line. And now it is not purplish at all. This one is too dark. I think that I do choose Plum 048, although I have placed that one at a very different position myself.

In light of this quote, it seems to be confirmed again that the differences in tint between lines were hardly visible for some of the participants, and that the purplish hue of the blue present over the entire chromatometer was regarded as a more important selection criterium. In future research, it could be investigated if participants would select different pencils when they were presented with a pencil case that provided more nuances of purplish blues compared to the pencil case used for this study.

Other participants selected the pencil Admiral blue 061 as the pencil that best matched the perceived colour for the dark blues. Admiral blue 061 was chosen at both distances, as well on line 1 as on line 3 of the chromatometer, but never at both positions by one and the same person. The two participants who selected Admiral blue 061 as the blue at the shorter distance on the chromatometer both selected a much darker blue at the further distance (Sapphire 039 and Dark indigo 031), contrary to Sowerby's expectations, who indicated that tints would become less saturated at further distances. One of the participants remarked to see almost no difference between the pencils Aegean blue 033 and Admiral blue 061 (see also figure 3.11 to compare colours). This participant selected Aegean blue 033, but also chose a darker blue, Plum 048, at the further distance, also contrary to Sowerby's expectations.

The participant who selected Admiral blue 061 as the blue at the further distance on the chromatometer chose - in line with Sowerby's expectations - a darker pencil for the shorter distance: Plum 048, although Plum 048 is not as dark as Sapphire 039 and Dark indigo 031.

What is also interesting, is that the purplish blue Byzantium 069 was selected for a distance at line 1, the uppermost wedge of the chromatometer, while no purplish tints were selected for the distance on the lower line 3. This may indicate that participants perceived this dark blue as more purple when the fringe of colour was thicker, because of being generated by a thicker patch of black.

In sum, two observations about the applicability of Sowerby's method can be made regarding the selected pencils for the colour dark blue. Firstly, three participants were unable to perceive sufficient difference in tint between line 1 and 3 to select different pencils for these two lines. This is in concert with the statements given in experiment 3: that for the top 3 lines differences in saturation were hardly perceivable. Secondly, participants who indicated a difference by means of selecting different pencils, sometimes chose a combination contrary to Sowerby's intent: 30% of the participants perceived a darker colour blue on the third line compared to the first line. 40% of the participants, however, selected a darker blue pencil for the first line compared to the one selected for the third line, which corresponds with Sowerby's vision on the working of the chromatometer.

For magenta, only pink pencils were selected, indicating that at this distance all participants perceived a secondary colour, caused by overlap between the red and blue colours on the chromatometer. However, participants were in this case neither unanimous about which pencil resembled this colour the clearest (see diagram 5 on the next page).

Diagram 2: selected pencils for the colour light blue

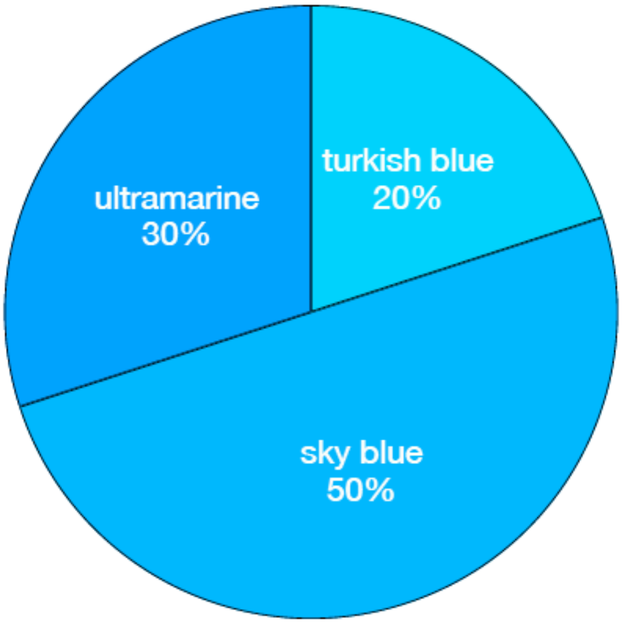


Diagram 5: selected pencils for the colour magenta

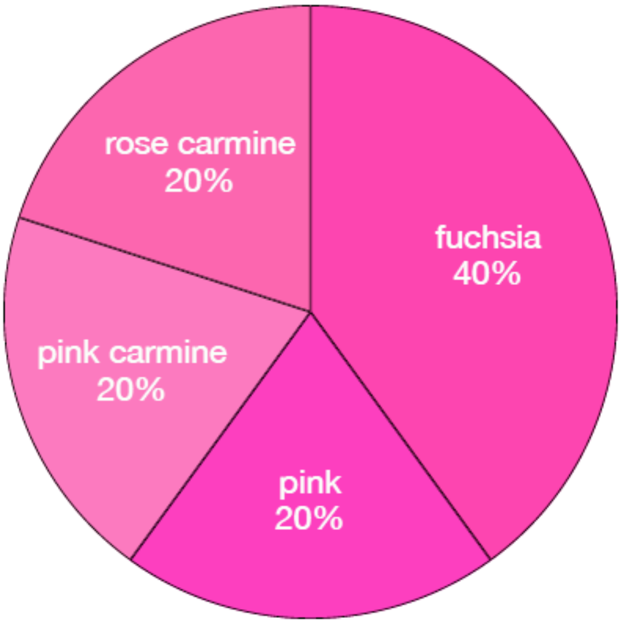


Diagram 3: selected pencils for the colour dark blue 1

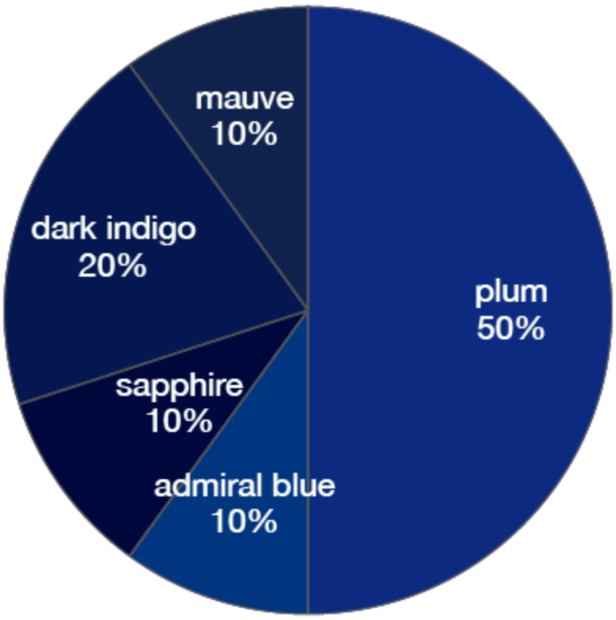


Diagram 4: selected pencils for the colour dark blue 2

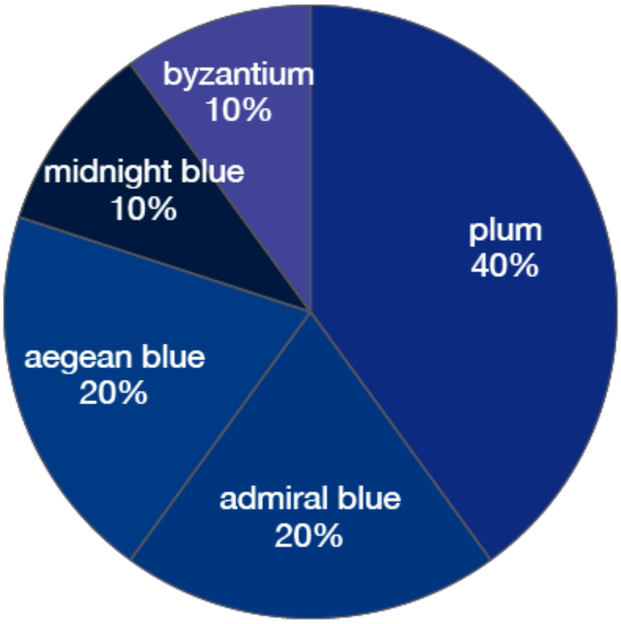


Figure 3.11: The pencils participants selected during experiment 5 (photo by dr. David Baneke).

Conclusion

The first question examined in this study was if Sowerby's method would lead to standardised results among participants. Already in experiment 3, it became clear that participants perceived different colours and tints of colour at one and the same position on the chromatometer. Therefore, it is not surprising that the positions at which participants marked to see certain tints of a colour as presented to them in experiment 4 diverged greatly. An additional problem with Sowerby's method turned out to be that participants indicated hardly to perceive any difference in tint for a large part of the chromatometer. This made it an arbitrary exercise to select one exact distance on the chromatometer at which a colour was perceived within the broader length range at which participants perceived the tint in question.

Also when it came to decoding colours in experiment 5, it became clear that participants perceived different tints of the given colour at the same position, resulting in the selection of a range of differently coloured pencils. Furthermore, this experiment proved that although all participants had indicated to see that the tints of colour on the chromatometer gradually became less saturated with diminishing thickness of the black productors, some of them selected more saturated tints for thinner parts of the chromatometer.

In conclusion, it can be unambiguously stated that this operationalisation of Sowerby's method does not lead to standardised results that can be communicated universally between participants.

One remark on the influence of environmental factors on this study, however, should be made. For this study, it was attempted to keep the amount of incident lighting constant for all participants. Therefore, all participants executed the experiments in the same room, and a room without windows was selected so that no sunlight could enter the room. Still, the door to the corridor contained a window through which light from the led lamps in the corridor could enter the room. At some days at which experiments were conducted, the lamps in the corridor were on, and at some days they were off. This can have had a small effect on the total amount of incident light a participant perceived while performing the experiments.

There was, however, an influential factor adding more to the amount of incident light present during different sessions: during the weeks in which the experiments were performed, the fluorescent tubes in the Buys Ballot Building were changed for LED-lamps. Although the fluorescent tubes in the room used for the experiment were not replaced during the weeks in which the experiment was conducted, the strength of the illuminance in the entire building was adapted multiple times. Unfortunately, it turned out to be impossible to trace back which participants had performed the experiment under which lighting conditions. However, if the lighting had been a decisive factor influencing the results of participants, it would have been expected that clusters of similar results, generated by participants performing the experiment under similar lighting conditions at subsequent days, would have been visible in the data. This was not the case: results varied greatly on a day-to-day basis.

The fact that this operationalisation of Sowerby's method did not lead to standardised results, does however not imply that his method is not teachable to people. It could of course be the case that all participants understood how to execute the method based on the given instructions, and that they performed the explained method in a similar way. In that case deviations would be caused by differences in perception, and not because the method was too difficult to understand or execute. As Henderson remarked, people may have great difficulties generating the coloured fringes on the chromatometer when only this task is presented to them. However, in his book Sowerby does present various other experiments before explaining the use of the chromatometer. This study has shown that, when participants are first made familiar with a selection of these "preparatory experiments" in order to understand the basic assumptions underlying Sowerby's theory and method, this enables them to handle the prism in such a way that exactly the colours - although maybe not the tints - he intended can be generated on the chromatometer within a very short amount of time.

Furthermore, once familiar with the basic concepts and ideas underlying Sowerby's method, some of the subsequent and more complicated steps of the method presented themselves; participants were frequently able to figure out where to find the secondary colour green without the need for instruction, and one participant even managed to generate a ternary brown.

As I quoted Sowerby at the beginning of this chapter, he believed that "his scheme is in its nature perfect, and calculation, measure, &c. will prove it; but how far the limited powers of mankind will carry it, remains a desideratum."[230] Sowerby regarded his method to be perfect, and it turns out that participants are able to learn to perform the right movements with a prism when this is introduced to them in a step-by-step manner. However, a comparison of the measurements made by participants proved an outcome differently from Sowerby's ambitions: the results are far from standardised. Even when everyone uses the same materials and works in the same environment, the limited powers of mankind strongly influence what distances are reported and what colours are selected, it turns out.

Nonetheless, the participant study provided many valuable insights into Sowerby's methodological assumptions and about the requirements for a method to lead to standardised results. In the conclusion of my thesis, I shall elaborate on the discovered methodological assumptions, and how these are related to the assumptions we discovered in earlier chapters. Furthermore, I shall reflect on the insights about standardisation I gained during this participant study.

[230] Sowerby, p. 30.

Conclusion

Sowerby encountered a problem that many of his eighteenth- and nineteenth-century contemporaries, artists as well as natural philosophers, faced: the instability of coloured pigments. The deterioration of plant- and mineral based pigments in time obscured the ability to convey the colours that one had intended to communicate. Sowerby was dissatisfied with the solutions other savants had come up with. He ridiculed Werner's idea to describe colours with words. Neither did he want to progress further on another route that displayed so much trouble: an in his eyes fruitless attempt to stabilise unstable pigments.[231] I argued in my thesis that based on his dual background as a natural philosopher as well as an artist, Sowerby was able to develop a method that combined knowledge of the mixing properties of pigments, with the methodological knowledge to work with prisms to create colours out of light. Some fifty years after Sowerby published his *A New Elucidation of Colours, Original and Prismatic* (1809), Hermann von Helmholtz (1821–1894) made clear that light and pigments would obey different laws: light mixes additively, and pigments subtractively.[232] Modern scholars, however, have found an exception to this rule: when border colours at the interfaces of black and white are generated out of light with the help of a prism, this light phenomenon obeys the laws of subtractive colour mixing, just as pigments do.[233] Science does not progress teleologically; it moves between different frameworks to explain the world around us, with different dominant theories. When it comes to theories about colours, our current ideas have cycled back to an assumption that Sowerby fully exploited: pigments and light can mix in a similar manner, and they obey the same laws of nature.

In the introduction, I remarked that a full picture of the diversity of colour theories developed in early nineteenth-century England is currently lacking. Although Sowerby and Goethe investigated effects of border colours through prisms around the same time, I hope that my thesis has shown that Sowerby's underlying theoretical ideas looked nothing like theoretical writings of Goethe. Thereby, I have not only added insight into different approaches to the study of border colours in the nineteenth century, but also contributed to our understanding of Goethe's experiments and assumptions regarding colour to a larger extent. Only when alternative approaches are investigated, and the diversity of ideas circulating in a certain period are mapped to a fuller extent, it can be appreciated that explanations presented in dominant theories are not the only way in which the world can be perceived and understood. A similar conclusion can be drawn from the comparison between Sowerby's and Newton's explanations of colour phenomena. As historian of science Alan E. Shapiro has remarked, in Newton's *Opticks* it is sometimes very difficult to separate his experiments from his theorising about them; "it is naive to think that Newton is presenting reports of simple observation that one is free to interpret as one wishes."[234] Because Newton's theory dominates our modern ideas about colours, it can be difficult to explicate what assumptions are build into his theory, and therefore are extant within our modern perception of colour phenomena. Presenting Sowerby's theory as an alternative, however, I hope to have made the reader aware of some assumptions underlying Newton's theory that had not been explicated before, and may also prove insightful to understanding our own beliefs about the working of colour to a fuller extent.

Below I shall elaborate more on the value of an in-depth study of Sowerby's colour theory. But before we can appreciate this value, and to enable us to place Sowerby's theory within the larger field of colour theories in his time, we first needed insight into the theory itself. And many of the insights Sowerby provides us with in his *Elucidation*, have remained elusive in earlier scholarship. Therefore, in my thesis I have investigated the theoretical, material and methodological assumptions underlying his theory from an interdisciplinary perspective. In chapter one and the beginning of chapter two of my thesis, I have mainly focused on explicating the theoretical assumptions that underly Sowerby's theory about colour, and how these are

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[231] Sowerby, *A New Elucidation of Colours,* p. 46-47.

[232] Robert A. Crone, *A history of color: the evolution of theories of light and color*. Springer Science & Business Media, 2012, p. 138-140.

[233] Pieter Johannes Bouma, *Physical aspects of colour: An introduction to the scientific study of colour stimuli and colour sensations.* Macmillan, 1971, p. 117.

[234] Alan E. Shapiro, "The gradual acceptance of Newton's theory of light and color, 1672–1727." *Perspectives on Science* 4.1 (1996), p. 90.

implemented in his chromatometer design and his method of generating colours with a prism. Thereafter, I examined the influence of some of Sowerby's material assumptions on the working of his chromatometer method. In chapter three, I asked participants to perform a selection of experiments from the *Elucidation*, and I tested if communication about colours would give standardised results as Sowerby aimed for. The process of designing this participant study, as well as the performance and responses of the participants, gave me insight in methodological assumptions underlying Sowerby's theory. However, a theory of course is not merely a bunch of isolated theoretical assumptions, material assumptions, and methodological assumptions glued together. Assumptions from all three categories influence each other, and therefore in this conclusion I shall synthesise what the chapters taught us about these assumptions, which form the elements of the coherent whole that is Sowerby's colour theory. Furthermore, I shall provide some additional details, observations and comments from the participant study, since I expect that these can best be appreciated against the background of a synthesis of all Sowerby's assumptions that were collected throughout the chapters.

Synthesis of Sowerby's assumptions

Unlike Aristotelian and Newtonian theories, Sowerby ascribed active agency to blackness and whiteness. Black would possess a strong colour collecting power, that turned the various coloured but imperceivable rays, encompassed in light, into visible colours. This colour collecting power of black could increase up to a maximum size, that Sowerby implemented in the formation of the chromatometer. Whiteness, on the other hand, possessed an instantaneous bleaching power, that would make colours appear fainter. Increasing the amount of white while gradually decreasing the amount of black, the interplay between black and white, would therefore enable the generation of all possible tints of the colours present on the chromatometer. During the participant study, it turned out that when separate black patches of clearly different sizes on a white paper were presented, all participants could agree that the larger black patches created more saturated colours, while the thinner patches created fainter colours. The chromatometer itself, due to its wedged shape on which the ratio of black to white changed very gradually, the effect on the perceived tints were so minimal that most participants could not perceive it anymore. This might be a major reason why the distances where participants reported to see a particular tint were far from standardised.

One of the central assumptions of Sowerby's theory, is that the colours generated out of light by a prism and pigment colours have the same properties. This leads Sowerby to use them interchangeably, as well in the phrasings of his observations in his book, as in practice. However, to Sowerby there was one big difference between light and pigments: in the long term, pigments would degrade, while light could freshly be summoned in all its bright saturation whenever one wished. Therefore, the use of a chromatometer seemed the ideal solution to Sowerby: the light that could be collected on a chromatometer would be able to exhibit all the good properties that pigments showed, while the bad property of degradation that pigments possessed could be avoided. Sowerby knew that this approach to work with colour was unconventional in his time. Therefore, he needed to convince the artists and natural philosophers who would adopt his method of its reliability and trustworthiness. As I argued in chapter one, Sowerby skilfully arranged the information in his *Elucidation* for this reason: by describing ordinary light phenomena that one can perceive in one's direct surroundings, he slowly habituates his readers to the idea that light has similar properties to pigments. Thereafter, he invites his readers to play with light phenomena themselves, in experiments that gradually would become more complex, getting involved in the process, Sowerby hoped that the reader would become convinced that prismatic rays could also be *used* in a similar manner as pigments.

The rays of light could be collected thanks to blackness. But which colours were collected, and how other colours could be generated from these primary colours, is also strongly theory-laden in Sowerby's theory. Red, yellow and blue are the primary colours that blackness can collect, according to Sowerby. All other colours can be created by mixing these primary colours. This would not only be the case for the pigments on a painters palette, but also for the rays of light that came out of a prism. In Sowerby's view, the three primary colours would be collected in clearly distinguishable bands on a chromatometer, and would not form a continuous spectrum such as Newton had claimed to perceive. Multiple participants described the colours they perceived on the chromatometer when looking through a prism, as if someone had placed distinct lines on the white paper with a marker. When one participant looked at the magenta colour, she indicated that it appeared to her as if someone had placed multiple stripes over each other with different marker colours. This modern rephrasing is fully in line with what Sowerby hoped one would perceive, and how he hoped that performers of his method would explain the generation of the mixing colour magenta. Other participants, however, objected to Sowerby's idea that there were distinct coloured bands perceivable. Instead, they claimed to perceive a plethora of shades of colours, above as well as below the chromatometer, that gradually changed as in a continuous spectrum. As I argued in my thesis, I am convinced that the perception of colour is theory-laden. In my opinion, this contrast in descriptions of the same phenomenon given by participants, shows that some participants easily accepted Sowerby's theory, and therefore saw the sharply distinctive coloured bands he intended one to see. Other participants might have become acquainted with Newton's idea of a continuous spectrum of light that dominates our modern perception of the visible spectrum, and therefore perceived a gradual continuum when looking at the border colours. In this instance, unraveling Sowerby's assumptions enabled me to use his theoretical ideas about border colours as a contrast to Newton's and our modern ideas about light, and thereby shed light on the ability of participants to perceive colours through different theories.

I explained that Sowerby strongly distrusted the use of pigments for communication about colours, since their instability made them prone to degradation, with colour change as a consequence. But he needed a means to create contrast between black and white for his chromatometer. And as I explained in chapter two, Sowerby therefore decided to turn back to the usage of black pigments. Therefore, his method does turn out to deviate less from the attempts of his contemporaries than Sowerby might have claimed. He too needed to experiment with pigments in an attempt to create pigment mixtures that were as stable as possible for the making of black patches. As Sowerby realised very well, there was an additional problem attached to the use of black pigments: even before degradation started, available black pigments were not capable of collecting the coloured rays as perfectly as pure black would. They needed to be turned into a deeper black by intermixing them with other coloured pigments. Strange enough, Sowerby fully trusted printers in this regard. Printers would know how to make the perfect black he aimed for without detailed instruction. And if one bought a chromatometer at his local printer, problems of pigment stability and differences in colour of papers and black pigment mixtures had suddenly vanished in Sowerby's mind. These chromatometers would be a valid tool for universally standardised communication about colours - although they were created with materials that Sowerby distrusted in other contexts.

Besides the chromatometer itself, a prism is essential to perform Sowerby's method. Sowerby believed that there existed a "right" orientation of the prism, at which the border colours on the chromatometer would look exactly as he intended. As Sowerby acknowledged, this "right" orientation of the prism (viewing angles and distances between chromatometer and prism and prism and observer) is prism-dependent. The chemical constitution of the glass will influence the dispersion, which at its turn determines the breadth of the coloured bands, thus the extent to which they overlap, and thereby the perceivable colours on the chromatometer. Sowerby asked the viewer to standardise this factor oneself, by turning and moving the prism until one perceives the "rightly" coloured bands through it. The means to convey a right position of the prism appeared to be problematic. Sowerby provides no images of what these "right" colours would look like. (Which is logical, since Sowerby did not trust pigments to retain a stable and therefore reliable colour over time.) And his verbatim description of these "right" colours proved insufficient for participants to work with in a standardised manner. Some participants remarked that the colours they saw through their prism could change if they changed position during the experiment, especially the red. In these cases I stressed that they should re-position themselves until they perceived the bands as red. For the red pencil "carmine", which almost all participants located at the same position, this might have worked. But this limited instruction might have contributed to the variety in positions at which various participants indicated to see the red pencil "sanguine".

Based on the above mentioned assumptions, Sowerby intended to have developed a method that would not only generate all possible tints of all imaginable colours in a more durable way, but that would also foster standardised communication about colours around the globe, and until the remotest ages. To cite the words with which Sowerby himself concludes his explanation of the chromatometer:

> This wedge therefore produces an infinite variety of these three primitive tints, from the most full and perfect to the most dilute, which may be measured precisely at pleasure in a very certain manner; so that every person may, in a common light, agree in pointing out a precise tint, even at distant parts of the world, if a similar wedge or chromatometer is

> used. Thus suppose the present to be a foundation, and for sake of accuracy was in general use, I would say, the red of Euphorbia Peplis for instance, (see *English Botany*, Tab. 2002.) is, or should be, equal to one inch, that is equal to the red given by such a width of black on white paper; and so of any tint or colour of any subject; and thus we may make conclusive comparisons, and learn what was intended, though time had caused it to fade.[235]

In the future, nobody would have to look at the discoloured image of his once vibrantly red coloured Euphorbia Peplis. Instead, the engraver could simply take up a prism and a chromatometer, locate the distance at which he/she saw this vibrant red, and note this beside a colourless depiction of the plant. Al readers could take up their chromatometers and prisms, locate this distance on the paper, and they would all see the red colour in a way that was much more reliable than any pigment could on the long term. At least, this is what Sowerby had hoped for.

Reflection on standardisation

One of the objectives of my thesis, was to investigate if Sowerby's method indeed - as he aimed - provides a means for standardised communication about colours. Therefore, his method would need to generate standardised results among various practitioners. Based on the results of the participant study, it can unambiguously be concluded that Sowerby's method - at least in the manner in which I presented it - does not lead to standardised results. However, the investigation of Sowerby's method provided me with more than just this conclusion. Allowing participants to perform his method, and using a variety of materials that were possible based on Sowerby's guidelines for its execution myself, provided me with valuable insights into the reasons why Sowerby's method did not lead to standardised results. Furthermore, these results made me contemplate what standardisation is, and what an investigation of Sowerby's method teaches us about the requirements for the achievement of a standardised method (to communicate about colours). I shall first highlight three examples of factors that might have contributed to the lack of standardisation that was achieved with Sowerby's method. Thereafter, I will provide some general reflections on the concept of "standardisation", that I learned based on my reconstructions.

Firstly, the participant study showed that the chromatometer as Sowerby designed it caused difficulties for the observers attempting to discern differences in tonality along its lines. But as some participants suggested, this could be compensated for by making a design that looked more like the staircase at the bottom for upper wedged part that creates the three primary colours red, yellow and blue as well.

Secondly, the participant study enabled me to see the gaps in Sowerby's instructions more clearly; the parts where Sowerby implicitly assumed that readers would know what to do - while they apparently did not. The additional tips I provided to the participants proved to be essential for most of them. But when these information gaps were filled, participants could handle the prism well enough to execute Sowerby's method.

Thirdly, in chapter two I pointed out that Sowerby specifies very little about the materials one should use for his method. But if the materials one should use were specified more clearly, differences in the bands various observers would create would disappear to a large extent. It might have taken some effort for Sowerby's contemporaries to obtain the right materials. But this is no different from modern colour standardisation practices. Many modern colour photographers are willing to pay a large sum of money to buy a colour checker that is made of exactly the right material colours so that it - hopefully - enables the photographer to create colour standardised images. The modern process might be different from Sowerby's, but the underlying ideas of what enables standardisation are the same.

Reflecting on these findings, I learned how important communication, specifications of materials, and a thorough explanation of the actions one should perform are. And in my opinion these insights are the key to standardisation in general. A truly standardised method thrives on usage of the same materials every time it is performed; on sufficient and clear communication

[235] Sowerby, p. 27.

about the procedure; and preferably a circular learning trajectory with feedback in which all steps are often repeated.

About standardisation from a historic point of view, there is an additional remark I want to make here. Sowerby thought that translating a colour into a longitudinal, measurable distance would make communication more reliable. Nowadays, using length measures such as the meter or inch is regarded as a reliable and standardised method. But we should realise that these measures that seem so natural and stable to us and Sowerby, also know a long history filled with negotiations, contest and governmental pressure before they became a neutral and easily usable standard for everyone.[236] Observing and experiencing how unnatural Sowerby's colour standardisation method feels to us, can provide us with more cross-temporal empathy for the people in earlier centuries who needed to transfer to standards that we nowadays regard to be natural.

Reflection on the divide between artisans and natural philosophers

In my thesis, I have focused mainly on one individual: James Sowerby. Although my comparisons with Newton and Goethe might have generated some new and valuable insights on their theoretical assumptions as well, I realise that focussing for a large part on one individual has a huge drawback: it makes it more difficult to make claims about colour history in general. Nonetheless, I hope that my in-depth research into Sowerby's colour theory can be a first step to challenge some assumptions and narratives in the field of colour history as a whole.

Within the field of colour history, historian of science Fokko-Jan Dijksterhuis is a strong proponent of the idea that knowledge of the mind and knowledge of the hand were not divided into two separate fields of knowledge. In "Perceptions of Colours by Different Eyes", he analysed what fruitful outcomes the interweaving of "painters knowledge" and "scholars knowledge" can have, when it comes to the development of a colour standardisation method. The scholar Lambert and painter Calau together developed a colour triangle, that consisted of many painted swatches of pigments in various mixtures. With this triangle, they hoped, people who wanted to communicate about colours would only need to point to a certain swatch, and everyone would know what colour was intended. Analysing the developmental process underlying this colour triangle, Dijksterhuis showed how the fields of knowledge in which Lambert and Calau were trained interacted, to create a device that none of them could have produced on his own. However, Dijksterhuis also pointed to the differences between the two men and what they found important based on their backgrounds as scholar or painter. Painter Calau could for instance not comprehend why exact measurements of pigments were needed according to the scholar Lambert.[237]

As I indicated in the introduction, Sowerby provides a case in which the strict categories of "painter" and "scholar" become untenable. Based on his dual background as a painter and a natural philosopher, he could develop a theory that harmonised knowledge from both fields, namely the prismatic theory of colours from Newton, and the three primary colours doctrine that was developed by painters. Sowerby was trained as an artist at the Royal Academy Schools, and knew a lot about painting and colours from his work as an engraver. At the same time, he was actively involved in the field of natural philosophy, engaging in multiple philosophical debates. Zooming in on his knowledge of colours, he closely followed the optical research of his contemporaries Young, Rochon and Prieur, and studied the Newton's *Opticks* in detail. In Sowerby's mind, there was no difference between material blacks and whites, and light and darkness, so he used them interchangeably. On top of that, the prismatic colours of natural philosophers and the pigment colours of painters obeyed the same laws of nature. Although we saw in the comparisons with Goethe that this contemporary of Sowerby did believe in a strong divide between painters colours and philosophers colours, the barrier between both fields of knowledge might be weaker than is currently narrated in colour research in the history of science. Merging both fields enabled Sowerby to develop his chromatometer method. But on top of that, it

236 Ken Alder, *The Measure of All Things*. Little, Brown, 2002, p. 2-5.

237 Fokko-Jan Dijksterhuis, "Perceptions of Colours by Different Eyes", In: *Colour Histories. Science, Art, and Technology in the 17th and 18th Centuries*, edited by Friedrich Steinle and Magdalena Bushart. Berlin, Boston, De Gruyter, 2015, p. 33-35.

shows that he internalised both fields of knowledge. With my thesis, I hope to have made a promising first step for research that might further revise the old narrative that imagines a strong dichotomy between artisans and natural philosophers.

Reflections on an interdisciplinary methodology

To investigate Sowerby's method in depth, and understand a method that combines many different fields of knowledge, I needed to adopt an interdisciplinary and unusual approach myself. I hope that my thesis will inspire and enhance more interdisciplinary and collaborative research within and with the field of colour history. Participants studies to test perception of colours are commonly conducted in modern colour studies. In my opinion, they are not that different from reconstructions of historical experiments in which larger groups of people are invited to participate. However, to my knowledge these fields have not interacted before. I hope that my thesis has shown that interweaving these two strands of research can generate an interesting hybrid methodology to study historical experiments about the perception of colour. On the same tier, although combining colorimetric analyses with an attempt to understand the properties of materials used for a historical method might have been challenging, I nevertheless hope that my attempt in this regard might inspire historians to try implementing formulae alien to their standard toolkit into their research.

The multidisciplinary attempt to bring methodologies of various disciplines together in research of Sowerby's method furthermore evoked some questions about current practice in the separate disciplines that I tried to combine, mainly in the discipline of colorimetry. I expect that various disciplines might benefit from interdisciplinary discussions about best practice. In this conclusion, I would like to detail on one of these cases.

In order to determine colorimetric standards such as the ΔE I used in chapter two, colorimetrists execute participant studies. In many of these studies, two swatches of colour are presented to the participants on a digital screen. They are asked to change the colour of one of these swatches with the help of colour manipulation switches until it exactly matches the colour of the other patch in their perception.[238] These and similar colour perception studies are regarded to be neutral: the performance of the participants would not be influenced by their cultural background, ideology, or theoretical assumptions about colour. By comparing the observations of Sowerby, Newton and Goethe during similar experiments, I have shown that their theoretical assumptions about colour strongly influenced what colours they perceived. A fundamental difference between the experiments of these three savants and colorimetric participant studies, is that Sowerby, Newton and Goethe used these experiments in an attempt to understand the working of nature. Their experiments were embedded in a strife for a higher goal: understanding the world around them. Colorimetric research does not strife for this goal, nor is this asked of participants.

However, the interdisciplinary way in which I combined and integrated colorimetric standards and historical research, made me wonder if these participant-studies in colorimetric research are indeed entirely value free. I expect that it would be insightful to investigate if these colorimetric participant studies are not to some extent influenced by the theory-laden observations of participants. If this indeed would be the case, I would argue that it is best to investigate and explicate the influence of theory-ladenness on this type of experiments. And I propose that my thesis might provide a first step into discovering the extent to which theory-ladenness influences the perception of participants. Above I explained that my own participant study to some extent shed light on the theoretical assumptions that guided the descriptions of the coloured bands participants perceived while reworking Sowerby's experiments. I expect that these types of experiments can form a fruitful starting point for development of tests for the theory-ladenness of participants in colorimetric studies. Thereafter, the standard colorimetric tests could be performed, and it could be checked if there are differences in results for groups with different colour theories in mind.

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[238] Bouma, p. 15, 186; Ming Ronnier Luo, Guihua Cui, and Bryan Rigg. "The development of the CIE 2000 colour-difference formula: CIEDE2000." *Color Research & Application: Endorsed by Inter-Society Color Council, The Colour Group (Great Britain), Canadian Society for Color, Color Science Association of Japan, Dutch Society for the Study of Color, The Swedish Colour Centre Foundation, Colour Society of Australia, Centre Français de la Couleur* 26.5 (2001): 340-350.

Somewhere during the nineteenth century, the universal savant who knew everything would have been replaced by a number of specialists - this fitted well in our new discipline-divided structure for science. Scholars such as the historian of science Gijsbert van de Roemer have pointed out how difficult it is to study implicit intellectual knowledge of early modern know-alls from the perspective of all these scholars that are trained in separate disciplines.[239] But during the first decades of the nineteenth century, savants that combined many strands of knowledge - such as Sowerby - were still around. And I hope that my in-depth study of Sowerby will provide inspiration to move back to a mode of science in which many strands of knowledge may be combined, so we can develop a fuller picture of the intellectual climate of the past.

[239] Gijsbert van de Roemer, *De geschikte natuur. Theorieën over natuur en kunst in de verzameling van zeldzaamheden van Simon Schijnvoet (1652-1727).* PhD dissertation, University of Amsterdam, 2005, p. 7.

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“He was prepared to ask remarkable favours of people, but always in the cause of science,”[240] writes his biographer about the endeavours of James Sowerby. In examining Sowerby’s colour theory in depth, I myself also asked many remarkable favours of people. Furthermore, I had great discussions with many people, who also provided me with additional, and sometimes unique, information.
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[240] Henderson, *James Sowerby: the enlightenment’s natural historian*, p. 13.

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Bibliography

Alder, Ken. *The Measure of All Things*. Little, Brown, 2002.

Ayers, Elaine. "Coded Colours: Botanical Histories of Colour Standardization," *The Site Magazine* 40.2 (2019): 24-39.

Baker, Tawrin. "Colour in Three Seventeenth-Century Scholastic Textbooks," In: *Colour Histories. Science, Art, and Technology in the 17th and 18th Centuries*, edited by Friedrich Steinle and Magdalena Bushart. Berlin, Boston, De Gruyter, 2015, p. 161-178.

Bilak, Donna. "Out of the Ivy and into the Arctic: Imitation Coral Reconstruction in Cross-Cultural Contexts." *Berichte zur Wissenschaftsgeschichte* 43.3 (2020): 341-366.

Bloks, Tanne. "Simon Schijnvoet, een veelzijdig verzamelaar." *Schrijverskabinet*. 29 November 2022. Accessible via: https://www.schrijverskabinet.nl/artikel/simon-schijnvoet/

Bouma, Pieter Johannes. *Physical aspects of colour: An introduction to the scientific study of colour stimuli and colour sensations.* Macmillan, 1971.

Bushart, Magdalena, and Friedrich Steinle. "Introduction." In: *Colour Histories. Science, Art, and Technology in the 17th and 18th Centuries*, edited by Friedrich Steinle and Magdalena Bushart. Berlin, Boston, De Gruyter, 2015, p. V-IX.

Chang, Hasok. "How historical experiments can improve scientific knowledge and science education: The cases of boiling water and electrochemistry." *Science & Education* 20 (2011): 317-341.

Conklin, Lawrence H. "James Sowerby, his publications and collections." *The Mineralogical Record* 26.4 (1995): 85-106.

Crone, Robert A. *A history of color: the evolution of theories of light and color.* Springer Science & Business Media, 2012.

Daston, Lorraine, and Peter Galison. *Objectivity*. Zone Books, 2010.

Davids, C. A, et al. *Rethinking Stevin, Stevin Rethinking : Constructions of a Dutch Polymath*. Brill, 2021.

Davy, Humphry. "Letter from Sr. Humphry Davy to Mr. James Sowerby," 1 July 1800. The Sowerby Collection 1739-1985. Natural History Museum, London.

Dijksterhuis, Fokko-Jan. "Perceptions of Colours by Different Eyes", In: *Colour Histories. Science, Art, and Technology in the 17th and 18th Centuries*, edited by Friedrich Steinle and Magdalena Bushart. Berlin, Boston, De Gruyter, 2015, p. 23-42.

Dijksterhuis, Fokko-Jan. "Werelden van vernuft." Inaugural lecture, Vrije Universiteit Amsterdam, March 3 2017.

Dolan, Brian. "Pedagogy through print: James Sowerby, John Mawe and the problem of colour in early nineteenth-century natural history illustration." *The British journal for the history of science* 31.3 (1998): 275-304.

Donovan, Arthur. *Antoine Lavoisier: Science, Administration, and Revolution*. Cambridge University Press, 1996.

Ducheyne, Steffen, “Facing the Limits of Deductions from Phenomena: Newton’s Quest for a Mathematical-Demonstrative Optics,” In: *The Main Business of Natural Philosophy : Isaac Newton’s Natural-Philosophical Methodology*. Springer, 2012.

Dupré et al. “Introduction.” In: *Reconstruction, Replication and Re-Enactment in the Humanities and Social Sciences*, edited by Sven Dupré, et al., Amsterdam University Press, 2020, p. 9-34.

Fernandez, Alicia, and Isabelle Charmantier, “Colours of Burlington House – A Chronicle.” *The Linnean Society of London*, 16 August 2017, https://www.linnean.org/news/2017/08/16/16th-august-2017-colours-of-burlington-house-a-chronicle. Accessed 21 October 2023.

Findlen, Paula. *Athanasius Kircher: the last man who knew everything*. Routledge, 2004.

Fors, Hjalmar, Lawrence M. Principe, and H. Otto Sibum. "From the library to the laboratory and back again: Experiment as a tool for historians of science." *Ambix* 63.2 (2016): 85-97.

Goethe, Johan Wolfgang von. *Goethe's Colour Theory,* translated by Charles Lock Eastlake. London, John Murray, 1840.

Goethe, Johann Wolfgang von. *Zur Farbenlehre*. Vol. 1. Tübingen, 1810. *Deutsches Textarchiv*. https://www.deutschestextarchiv.de/goethe_farbenlehre01_1810 Accessed 20-02-2024.

Goethe, Johann Wolfgang von. *Zur Farbenlehre*. Vol. 2. Tübingen, 1810. *Deutsches Textarchiv*. https://www.deutschestextarchiv.de/book/show/goethe_farbenlehre02_1810 Accessed 20-02-2024.

Golinski, Jan. "Humphry Davy: the experimental self." *Eighteenth-Century Studies* (2011): 15-28.

Golinski, Jan. *The Experimental Self: Humphry Davy and the Making of a Man of Science.* University of Chicago Press, 2016.

Green, Phil. "Colorimetry and colour difference." In: *Fundamentals and Applications of Colour Engineering*, Wiley, 2023, p. 27-52. https://doi.org/10.1002/9781119827214.ch2

Hagendijk, Thijs. *Reworking recipes: reading and writing practical texts in the early modern arts*. PhD dissertation, Utrecht University, 2020.

Hanson, Norwood Russell. *Patterns of Discovery: An Inquiry into the Conceptual Foundations of Science*. Cambridge University Press, 1975.

Heise, Frederik. “Goethe – Farbige Schatten (1810).” In: *Kanonische Experimente der Physik: Fachliche Grundlagen und historischer Kontext*. Berlin, Heidelberg: Springer, 2022, p.107-124.

Henderson, Paul. "James Sowerby: meteorites and his meteoritic sword made for the Emperor of Russia, Alexander I, in 1814." *Notes and Records of the Royal Society* 67.4 (2013): 387-401.

Henderson, Paul. *James Sowerby: the enlightenment's natural historian*. Royal Botanic Gardens, Kew, 2015.

Hendriksen, Marieke. "Rethinking performative methods in the history of science." *Berichte zur wissenschaftsgeschichte* 43.3 (2020): 313-322.

Hentschel, Klaus. "Verengte Sichtweise: Folgen der Newtonschen Optik für die Farbwahrnehmung bis ins 19. Jahrhundert." *Perspectives on Science* 4 (1996): 59-140.

Huistra, H.M., T. Cocquyt, H.N. Asper and T. van der Valk, “Proeven van Vroeger: Een ANW-module wetenschapsgeschiedenis”, *NVOX* 37 (2012): 422–424.

Hunter, Dard. *Papermaking: the history and technique of an ancient craft*. Courier Corporation, 1978.

Kingslake, R., and P. F. DePaolis. “New Optical Glasses.” *The Scientific Monthly*, vol. 68, no. 6, 1949, pp. 420–23.

Klein, Ursula. "A Revolution that never happened." *Studies in History and Philosophy of Science Part A* 49 (2015): 80-90.

Klein, Ursula. “Artisanal-scientific Experts in Eighteenth-century France and Germany”, *Annals of Science*, 69:3 (2012): 303-306. DOI: 10.1080/00033790.2012.675195.

Kleinwächter, Tanja C., Sarah Lowengard, and Friedrich Steinle, eds. *Ordering Colours in 18th and Early 19th Century Europe*. Springer Nature, 2023.

Krimbas, C., B. H.W. Lack and D.J. Mabberley, “The Flora Graeca Story.” *The Historical Review/La Revue Historique*, 1 (2005): 275–285. https://doi.org/10.12681/hr.179

Krünitz, Johann Georg. *Oekonomische encyklopädie*. Vol. 11. J. Pauli, 1777.

Kuehni, Rolf G.. *Color Space and Its Divisions: Color Order from Antiquity to the Present*. Wiley, 2003.

Leonhard, Karin. “Flowering Colour — Still Life Painting and Baroque Colour Theory.” In: *Colour Histories. Science, Art, and Technology in the 17th and 18th Centuries*, edited by Friedrich Steinle and Magdalena Bushart. Berlin, Boston, De Gruyter, 2015, p. 261-294.

Loon, Annelies van, Petria Noble, and Aviva Burnstock. "Ageing and deterioration of traditional oil and tempera paints." In: *Conservation of Easel Paintings*, edited by Joyce Hill Stoner and Rebecca Anne Rushfield. Routledge, 2020, p. 216-243.

Luo, Ming Ronnier, Guihua Cui, and Bryan Rigg. "The development of the CIE 2000 colour-difference formula: CIEDE2000." *Color Research & Application: Endorsed by Inter-Society Color Council, The Colour Group (Great Britain), Canadian Society for Color, Color Science Association of Japan, Dutch Society for the Study of Color, The Swedish Colour Centre Foundation, Colour Society of Australia, Centre Français de la Couleur* 26.5 (2001): 340-350.

Marsden, Ben. “Engineering Science in Glasgow: Economy, Efficiency and Measurement as Prime Movers in the Differentiation of an Academic Discipline.” *The British Journal for the History of Science*, 25.3 (1992): 319-346.

Nawrath, Dennis. “Auf den Spuren Newtons - Experimente zur Farbzerlegung und Farbmischung mit Prismen.” *Naturwissenschaften im Unterricht Physik* 110 (2009): 16-20.

Nawrath, Dennis. "Die Analyse von Newtons Prismenexperimenten zur Untersuchung von Licht und Farben (1672) mit der Methode der Replikation–Ein Erfahrungsbericht." In: *Experimentelle Wissenschaftsgeschichte,* edited by O. Breidbach, P. Heering, M. Müller, & H. Weber. München, Wilhelm Fink Verlag, 2010, p. 73-105.

Nawrath, Dennis. "Die prismatische Farbzerlegung durch Isaac Newton." In: *Kanonische Experimente der Physik: Fachliche Grundlagen und historischer Kontext*. Berlin, Heidelberg: Springer, 2022, p. 35-47.

Newman, William R, and Lawrence M Principe. *Alchemy Tried in the Fire: Starkey, Boyle and the Fate of Helmontian Chymistry*. University of Chicago Press, 2002.

Newton, Isaac. *The Second Book of Optics, part I: Observations concerning the Reflexions, Refractions, and Colours of thin transparent Bodies*, London, Printed for William Innys at the West-End of St. *Paul's,* 1704.

Nieto-Galan, Agusti. "Between Craft Routines and Academic Rules: Natural Dyestuffs and the "Art" of Dyeing in the Eighteenth Century." In: *Materials and expertise in early modern Europe: between market and laboratory*, edited by Ursula Klein and Emma C. Spary, University of Chicago Press, 2010, p. 321-353.

Nussbaumer, Ingo. *Zur Farbenlehre: Entdeckung der unordentlichen Spektren*. Vienna, Edition Splitter, 2008.

Parkinson, Neil. *The History of Colour: A Universe of Chromatic Phenomena*. United Kingdom, Frances Lincoln, 2023.

Prieur, C. A. "XXIII. On the decomposition of light into its most simple elements, being part of a work upon colours." *Philosophical Magazine Series* 1, 28:110 (1807): 162-170. DOI: 10.1080/14786440708563498.

Prieur C. A. "XXX. On the decomposition of light into its most simple elements, being part of a work upon colours." *Philosophical Magazine Series* 1, 28:111 (1807): 210-219. DOI: 10.1080/14786440708563508.

Principe, Lawrence M. "Apparatus and Reproducibility in Alchemy." In: *Instrument and Experimentation in the History of Chemitry*, edited by Frederic L. Homes and Trevor H. Levere, MITPress, 2000, p. 55-74.

Rang, Matthias. "Coincidentia oppositorum - a thought on the relationship between Goethe's theory of colors and Newtons optics and todays physics." In: *Experiment Colour - Goethe, Newton and Optics,* edited by C. Gerodetti and Z. Nordien. Kosmos Förlag, 2011, p. 10-24.

Rang, Matthias, Oliver Passon, and Johannes Grebe-Ellis. "Optische Komplementarität. Experimente zur Symmetrie spektraler Phänomene." *Physics Journal* 16 (2017): 43-49.

Reissland, Birgit. "A Practical Guide to the Production of Black Pigments and the Preparation of Black Watercolours, 1350–1700." In: *Burgundian Black: Reworking Early Modern Colour Technologies*, edited by Jenny Boulboullé and Sven Dupré. Santa Barbara, EMC Imprint, 2022.

Renker, Armin. *Das Buch Vom Papier: Von Armin Renker.* Insel-Verlag, 1951.

Ribe, Neil, and Friedrich Steinle. "Exploratory experimentation: Goethe, Land, and Color Theory." *Physics today* 55.7 (2002): 43-49.

Rochon, Allexis. "III. Observations on platina, and its utility in the arts, together with some remarks on the advantages which reflecting have over achromatic telescopes." *Philosophical Magazine Series* 1, 2:5 (1798): 19-27. DOI: 10.1080/14786449808676871.

Rochon, Alexis. "XI. Observations on platina, and its utility in the arts, together with some remarks on the advantages which reflecting have over achromatic telescopes." *Philosophical Magazine Series* 1, 2:6 (1798): 170-177, DOI: 10.1080/14786449808676901.

Gijsbert van de Roemer, *De geschikte natuur. Theorieën over natuur en kunst in de verzameling van zeldzaamheden van Simon Schijnvoet (1652-1727).* PhD dissertation, University of Amsterdam, 2005.

Roemer, Gijsbert M. van de. "The Serious Naturalist and the Frivolous Collector: Convergent and Divergent Approaches to Nature in D'Amboinsche Rariteitkamer." *Early Modern Low Countries* 3.2 (2019): 208-233.

Roy, Monique S., et al. "Color vision and age in a normal North American population." *Graefe's archive for clinical and experimental ophthalmology* 229 (1991): 139-144.

Schaffer, Simon. "Glass works: Newton’s prisms and the uses of experiment." In: *The Uses of Experiment: Studies in the Natural Sciences,* edited by David Gooding, Trevor Pinch and Simon Schaffer. Cambridge university press, 1989, p. 67-104.

Schatzberg, Eric. *Technology: Critical History of a Concept,* University of Chicago Press, 2018.

Schiebinger, Londa. “The Philosopher’s Beard: Women and Gender in Science.” In: *The Cambridge History of Science*, edited by Roy Porter, vol. 4, Cambridge University Press, 2003, p. 184-210.

Shapin, Steven. “The Image of the Man of Science.” In: *The Cambridge History of Science,* Volume 4 edited by Roy Porter, Cambridge University Press, 2003, p. 159-183.

Shapiro, Alan E. "Artists' colors and Newton's colors." *Isis* 85.4 (1994): 600-630.

Shapiro, Alan E. "The gradual acceptance of Newton’s theory of light and color, 1672–1727." *Perspectives on Science* 4.1 (1996): 59-140.

Sowerby, James. *A new elucidation of colours, original, prismatic, and material: showing their concordance in three primitives, yellow, red, and blue, and the means of producing, measuring, and mixing them: with some observations on the accuracy of Sir Isaac Newton.* London, Richard Taylor and Co.,1809.

Sowerby, James. *British mineralogy, or, Coloured figures intended to elucidate the mineralogy of Great Britain*, vol. 1, London, Richard Taylor and Co., 1802.

Sowerby, James. “3-2: Prospectus of *A New Elucidation and Arrangement of Colours*,“ and “3-3: Notice of Sowerby’s Chromatometry lecture.” 1 December 1808. Manuscript letters to members of the Sowerby Family: Box 5: Unattributed and Miscellaneous, DM1186 - Eyles Collection relating to the history of geology, Special Collections, University of Bristol Library.

Steinle, Friedrich. “Colour Knowledge in the Eighteenth Century. Practice, Systematisation, and Natural Philosophy.” In: *Colour Histories. Science, Art, and Technology in the 17th and 18th Centuries*, edited by Friedrich Steinle and Magdalena Bushart. Berlin, Boston, De Gruyter, 2015, p. 43-67.

Steinle, Friedrich. "Experiments in history and philosophy of science." *Perspectives on science* 10.4 (2002): 408-432.

Stijnman, Ad. *Engraving and Etching, 1400-2000: A History of the Development of Manual Intaglio Printmaking Processes.* PhD dissertation, Archetype Publications, 2012.

Stijnman, Ad."Frankfurt Black: tryginon appelantes, faex vini arefacta et cocta in fornace." In: T*rade in Artists’ Materials: Markets and Commerce in Europe to 1700*, edited by Jo Kirby, Susie Nash and Joanna Cannon. London, Archetype, 2010, p. 415-425.

Stijnman, Ad. “The Colours of Black Printing Inks for Blockbooks” In: *Blockbücher des 15. Jahrhunderts: Eine Experimentierphase im frühen Buchdruck. Beiträge der Fachtagung in der Bayerischen Staatsbibliothek München am 16. und 17 Februar 2012*, edited by Bettina Wagner. Harrassowitz, 2013, p. 59-80.

Stuewer, Roger H. "A critical analysis of Newton's work on diffraction." *Isis* 61.2 (1970): 188-205.

Takuwa, Yoshimi. *A study on the role of experiments in Isaac Newton's optical research.* PhD dissertation, 2019.

Takuwa, Yoshimi. "The historical transformation of Newton's experimentum crucis: Pursuit of the demonstration of color immutability." *Historia Scientiarum* 23 (2013): 113-140.

Wijk, Helle, et al. "Colour perception among the very elderly related to visual and cognitive function." *Scandinavian Journal of Caring Sciences* 16.1 (2002): 91-102.

Wollaston, William Hyde. "XII. A method of examining refractive and dispersive powers, by prismatic reflection." *Philosophical Transactions of the Royal Society of London* 92 (1802): 365-380.

Yokoyama, Sho, et al. "Age-related changes of color visual acuity in normal eyes." *Plos one* 16.11 (2021): e0260525.

Young, Thomas. "Lecture XXXVII: On Physical Optics." In: *A Course of Lectures on Natural Philosophy and the Mechanical Arts. Illustrated, Etc*, Volume 1, reprint of 1845, p. 340-350.

Appendix: Instructions test-subject research

Thank you for participating! First of all, I shall explain to you what the goal of the study is.

Goal
In 1809 the mineralogist, botanist and engraver James Sowerby claimed to have developed a method with which scientists could determine colours and communicate about them in a standardised way. According to Sowerby, this could be achieved by using a *chromatometer* - which is just a piece of paper with black patched on it - and a prism in a lit environment.
For my master thesis, I am investigating if Sowerby's method is teachable, and whether it indeed leads to standardised results.

Description session
In order to investigate this, I will ask you to reconstruct (a part of) 5 of Sowerby's experiments. With the first three experiments, I will teach you how Sowerby's method works.
In the last two experiments I shall ask you to use Sowerby's method to name and decode colours.

Is everything clear so far? If so, we will start with the experiments.

Prism
On the table lies a prism. Now, you may place your fingers on the two opaque sides of the prism. Please only touch these sides for the remainder of the session. And can you check if there are no fingerprints visible on any of the other sides? If there are, please wipe them off.

Experiment 1
Please hold the prism horizontally like this. [*Instructor shows right orientation before the camera.*] Behind you is a beautiful white wall. Can you turn to the wall and direct the prism towards it as well? You might need to move a bit closer to the wall.

Tips in case needed:

- *Instructor explains that participant needs to turn the prism 90 degrees in case it is held vertically instead of horizontally*
- *Instructor explains that it works better to hold the prism between the thumb and index finger of one hand, instead of using the index fingers of both hands*

Do you see a white spot appearing on the wall?
If you tilt the prism up and down by turning your wrist, you should discover a second spot on the wall. Is this the case?
Do you see coloured stripes appearing in this second spot?

Tips in case needed:

- *Instructor repeats that the participant should move closer to the wall*
- *Instructor repeats that the prism should be held horizontally*
- *Instructor repeats to move wrist up and down*

If so, please describe as precisely as possible which colours you perceive in this spot.
Congratulations, you have completed the first experiment successfully!

Experiment 2
On the table you can also find a sheet of paper with three black patches on it. Can you place that sheet in front of you on the table, with the largest patch at your left, and the smallest patch on the right? *Instructor checks if the orientation of the sheet is correct.*
Please try now to look through the prism to the sheet of paper, and see if you can find the three patches in your field of view.
Do you perceive colours that resemble the colours you just saw on the wall?

Tips in case needed:

- *Instructor asks to hold the prism closer to ones eye*
- *Instructor suggests the participant that it might help to take his/her glasses off*
- *Instructor suggests to close one eye, and look through the prism with the other eye*
- *Instructor suggests that it might help to look only through the plane of the prism very close to one corner of the prism, and from there directly downwards to the paper*

- *Instructor advices that if the participant cannot find the colours, it might help to take the prism between the fingers of one hand, and slowly turn the prism about its horizontal axis until he/she sees colours appearing*

Can you describe as precisely as possible which colours you perceive?
Around some of the patches, the colours might be paler than around others. Do you perceive it that way?
If so, can you please indicate which patch is surrounded by the darkest colours, and which one by the palest?
Congratulations, you have completed the second experiment.

Experiment 3
Now, you may place the chromatometer in front of you. That is the sheet of paper with many black patches underneath each other, that become smaller to the right.
Also, there is a *staircase* present on the chromatometer. Please place the chromatometer in such a way that the staircase is placed the closest to you on the table. *Instructor checks if the orientation of the chromatometer is correct.*
If you look through the prism to the chromatometer, can you see the same coloured stripes you saw on the previous sheet of paper?

Now follows a little bit of explanation:
Because the coloured stripes are clearly distinguishable, Sowerby says the vertical height is of no importance. If someone says “red”, everyone would know at which stripe one should look. However, the horizontal distance is crucial according to Sowerby, because this distance determines the tint and shade of the colour one wants to describe.

Now, I want to ask you: allow yourself some time to look at the chromatometer. Focus on the top five lines. You can ignore the staircase for now. And after you looked at the chromatometer for some time, please indicate to me if you can perceive differences in the tint and shade of the colours between the broadest part of the chromatometer at the upper left, and the smallest part at the bottom right. Do you perceive differences for all colours? Do you perceive differences between other lines and on one line as well?

Experiment 4
In the last two experiments, I will ask you to use Sowerby’s method. First, I shall ask you to translate 5 colours into distances with his method. Thereafter, I shall ask you to decode 4 distances I determined in advance of this study back into perceivable colours.

On the table a pencil case is present, can you already open this? Furthermore, there is a sheet of paper present on top of which “experiment 4” is written, you can also take this.
The coding experiment, experiment four, consists of two parts: firstly, placing crosses on the chromatometer itself, and secondly determining distances on the chromatometer.

The first pencil you can take from the pencil case is “Lemon 015”, a yellow pencil.
If you look through the prism at the chromatometer, you can perceive yellow stripes - with possible different shades of yellow for different distances. I would like to ask you to look attentively at the colour present at the back of this pencil. Thereafter, please place a cross on the chromatometer at the exact spot on which you see this colour and shade the clearest.
Next, you can take the pencil named “Sanguine 006” from the set, a red pencil. Also for this pencil, please place a cross with it on the exact spot at which you see its colour and shade the clearest. And please write the code 006 close to this cross, since you are going to mark another red as well.
Please repeat this also for the pencils named “Crimson 058” (red), “Plum 048” (dark blue) en “Light green 010” (green).

Tip in case needed: “To find the green, you might have to look at the staircase now.”

If you like, you are allowed to change the positions at which you placed a cross for one or more of the colours now. Once you are satisfied with the positions where you placed your marks, we will continue with the second part of the experiment.

Finished? Great!
As I indicated earlier, to Sowerby the horizontal distance on the chromatometer is crucial to be able to communicate about colours in a standardised way. In his opinion, in order to describe a colour exactly, all one needs is the name of the colour - so for instance yellow - and the horizontal distance on the chromatometer.
Furthermore, the chromatometer consists of multiple black patches, the so called “lines”. The uppermost line, that starts with a horizontal part, is called line number 1. The one underneath is line 2, and so on with the lowest one number 5. The staircase is numbered from 1 to 5 in the same way. *Indicate that participants are allowed to note the numbers at the beginning of each line if they ask about it.*
Please note for each colour you just marked with a cross on the chromatometer in the table on the notation sheet the number of the line in which you placed this cross. For the crosses placed in the staircase, please also write the word “staircase” in the table.
Now, you can take the ruler from the table. Please measure for every pencil with which you placed a cross on the chromatometer the distance from the beginning of the line - so the left side of the black patch - up to the place where you placed the cross in centimeters with one decimal after the comma. And note these distances in the last column of the table.

Congratulations, you completed the 4th experiment.

Experiment 5
Now we move to the 5th and last experiment: the decoding-experiment. I noted a few colours on the notation sheet, and a specific distance on one of the lines of the chromatometer.
Can you take the pen from the table, and place a vertical line at the position at which you measure these distances? Please note also the name of the colour close to the vertical line.
Next, I ask you to take the prism again, and look through it to the place where you placed the vertical line. Please also take the pencil case again. And choose the pencil at the position where you placed a vertical line for light blue that matches the colour and shade you perceive the closest. Please take this pencil out of the set, and show it before the camera, with its name and code clearly visible. And please note the name and number of this pencil in the box reserved for this on the notation sheet.
Next, you can look through the prism to the vertical line you placed for the colour dark blue 1. Please also select for this colour the pencil that resembles the colour and shade you perceive the closest, and take that one out of the pencil case. Can you show it before the camera, with its name and code clearly visible? And can you please note the name and number of this pencil in the box reserved for this on the notation sheet? If you see multiple pencils that might match this colour, please select the one matching it the closest in the box, but you are allowed to list some other pencils behind the box. Can you explain why you made this choice?
Please repeat the procedure for the colour dark blue 2 as well.
Also for the vertical line you placed for “magenta”, please select the pencil that resembles the colour and shade you perceive the closest, and take that one out of the pencil case. Can you show it before the camera, with its name and code clearly visible? And can you please note the name and number of this pencil in the box reserved for this on the notation sheet?

Thank you, these were all the experiments I wanted to go through with you today.

Can you please write the number [X] in the upper right corner of all paper sheets, and put all pencils back into the pencil case?

Thank you very much for participating. I hope you enjoyed performing these experiments. In case you have any questions about the experiments or the study, you can ask them now.