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Pure Red. The Evolution of a Colour Idea in Trichromacy

«What does ‹simple redness› look like […]? How do you know the quality exists if it is not expressed by a certain colorant?» asks Ian Lawson with reference to the «simplicem ruborem» that, in 1613, the Jesuit mathematician Francis Aguilón looked for among common red colourants.[1] Similarly, Eckhart Heimendahl and Carl Friedrich von Weizsäcker formulate questions about Goethe's «ganz reines Roth»: «A ‹pure red›, what colour is that? […] Which idea of red is tacitly accepted as binding when one speaks of the basic colour red? […] Spectral red or purple-red?».[2]

In the same vein, our paper analyses these questions within a particularly important historical strand: the discussion of what specific material came closer to ‹simple›, ‹pure›, ‹true› or ‹perfect› red during the 18th century, and how that very notion emerged and was understood in trichromacy, a theory which claimed that three chromatic colours (red, blue, yellow) could produce all others.

Trichromacy was developed from painters' first-hand experience and then adopted in colour theories. While many painters supported this theoretical approach, they also knew that many brown, black, white and green hues existed as colourants. Yet some practitioners and scholars such as Jacob Christoff Le Blon (1667–1741) and Johann Heinrich Lambert (1728–1777) reduced the painters' palette to just three colourants to demonstrate the practicability of trichromacy. The right red hue was the most discussed one because it was available in the largest spectrum of colourants.[3] In the course of those discussions, the notion of ‹pure› red shifted most significantly from the 17th-century deep red of vermilion to the mid 18th-century magenta-coloured carmine.

In our paper, we shall present that remarkable development in detail and ask: What was meant by ‹simple›, ‹pure›, ‹true› or ‹perfect› red? What considerations and arguments did the historical actors present, in what practical and conceptual contexts? Was it due to the empirical mixing of colourants or did also theoretical investigations contribute to it? What possible consequences did this change of ‹pure›-red understanding have in science and practice? And, more generally, what was the background of naming those colours exactly ‹simple›, ‹pure›, ‹true› or ‹perfect›, i. e. with terms that could point to wider ontological frameworks and commitments? In pursuing those questions, our article presents first results of an ongoing research project that investigates the connections between colour names and colourants.[4]

Simple Colours in Trichromacy

The idea that a small number of colours can produce all others reaches back to painters' practical experiences with colour mixing. Rather explicit formulations of trichromacy can already be found in the Florentine Renaissance. Leon Battista

Alberti identified in the painters' practice four «colorum vera genera»: red, blue, green/yellow, and grey (i. e. white + black), discriminating the basic chromatic triad (red, blue and green/yellow) from the non-chromatic colours white and black.[5] From the early 17th century, such an approach was further developed and illustrated with diagrams in some general treatises on light and colour, e. g. in Aguilón's *Opticorum Libri Sex*, Athanasius Kircher's *Ars Magna Lucis et Umbrae* (1646) and Johannes Zahn's *Oculus Teledioptricus* (1685).[6]

Many trichromatists[7] assumed that not only colourants but also those colours called «colores apparentes», which were seen in rainbows, generated by lenses, glass containers filled with water, and prisms, followed the universal law of trichromacy.[8] This assumption based on the experience of painters with pigments and of natural philosophers with coloured glass panes: For instance, the mixing or superimposing of yellow and blue produce green.[9] While prismatic colours were described as more spectacular and brilliant than colourants, trichromatists rarely distinguished them[10] and sometimes claimed that skilled painters could imitate them with pigments.[11] The Dutch baroque art theory also formulated the arrangement and shine of rainbow colours as a model of colour harmony.[12] Similarly, some 18th-century trichromatists regarded the order of spectral colours as the pictorial paradigm for harmony.[13] However, the trichromatic theory as formulated in the 17th century was about hues and not colourants,[14] and thus the relationship between these colours was always a sensitive point often only discussed in passing.

In this regard, a look at the terminology is revealing. Trichromatists referred to the three main colours in different terms such as «Hooftverwen»,[15] «Hauptfarben»,[16] «couleurs principales»,[17] «prime or principal colours»,[18] «primitive colours»,[19] «couleurs primitives»,[20] or «colores simplices».[21] This last expression indicates the problem strikingly: The Latin word *simplicia* was widely used in 16th- and 17th-centuries medical and painting practices. *Simplicia* were plants, spices, minerals, roots, animals or animal products that constituted the basic materials for drugs and colourants.[22] To call the main trichromatic colours *simplices* disaccorded with the pictorial practice, where all colourants were considered ‹simple› and subsumed under colour groups (e. g. ultramarine or indigo under blue).

The issue is evident in some 17th-century painting manuals supporting trichromacy such as Johannes Scheffer's *Graphice, id est, de arte pingendi* (1669) and Willem Beurs' *De groote waereld in 't kleen geschildert* (1692). Scheffer indicated three «simplices colores» but listed six red, seven yellow and four blue colourants.[23] Similarly, Beurs highlighted three «main colours or main materials of the oil colours» (yellow, red, and blue) but provided altogether 18 colourants.[24] These examples are illustrative of the unresolved tension between primary hues and their matching colourants and seem to explain Aguilón's search for the «simplicem ruborem» among red pigments.

From the late 17th century onwards, a lively discussion arose on the subject. Philosophers, mathematicians and artists asked themselves what colourants could be primaries. Choices were based, e. g., on hue and chemical properties.[25] Yet, in the 18th century, these choices clashed with the first attempts to visualise trichromacy through colourant-mixing diagrams, and the challenge of defining the criteria of primary colours became strikingly blatant. These diagrams originated in the uncoloured ones published in the treatises on light and colours of Aguilón, Kircher and Zahn.

Trichromacy and Prismatic Colours

The leading question of this section is whether the three primaries could have been taken from the rainbow or optical experiments with the prism. As mentioned, trichromatists often referenced to the colours of the rainbow or those exhibited by the prism. Trichromacy's basic idea was that main colours can produce all others and especially some secondaries, such as green, purple, violet and orange.[26] These secondaries were also emphasised in general accounts on the colours in the rainbow or those produced by prisms or transparent bodies. In this context, the claim emerged that the three primaries red, yellow and blue were visible in prismatic and rainbow colours, interlaid by their mixtures as supported by Marin Mersenne and Kircher.[27]

Although neither prismatic nor rainbow colours offer any hints to an internal hierarchy, these authors explicitly introduced one: they attributed to three of these colours a more fundamental status and regarded the others as mixed. The aforementioned painters' experience with pigment mixing and scholars' experiences with coloured glass panes seemed to support the trichromatic hierarchy, which was thus easily transferred to ‹apparent› colours.

The central author to oppose that hierarchy was Isaac Newton. His philosophical/physical theory of light and colour (1672) argued that all spectral colours were «original and simple», while those created by their superposition were «compounded».[28] In *Opticks* (1704), Newton no longer distinguished an infinite number of simple spectral colours but only seven primaries, including green, orange and violet. Moreover, he presented a colour-mixing scheme and illustrated the seven spectral colours with ground pigments, thereby suggesting its universal applicability to spectral and material colours.[29] Hence, Newton's theory stood in direct opposition to trichromacy.

While many natural philosophers quickly adopted Newton's account, numerous scholars interested in colourants did not accept it easily. In open opposition to Newton's theory, some of them supported trichromacy for spectral colours. For instance, in 1758, the astronomer and cartographer Tobias Mayer presented a colourant-mixing scheme based entirely on trichromacy, whose primaries Mayer saw:

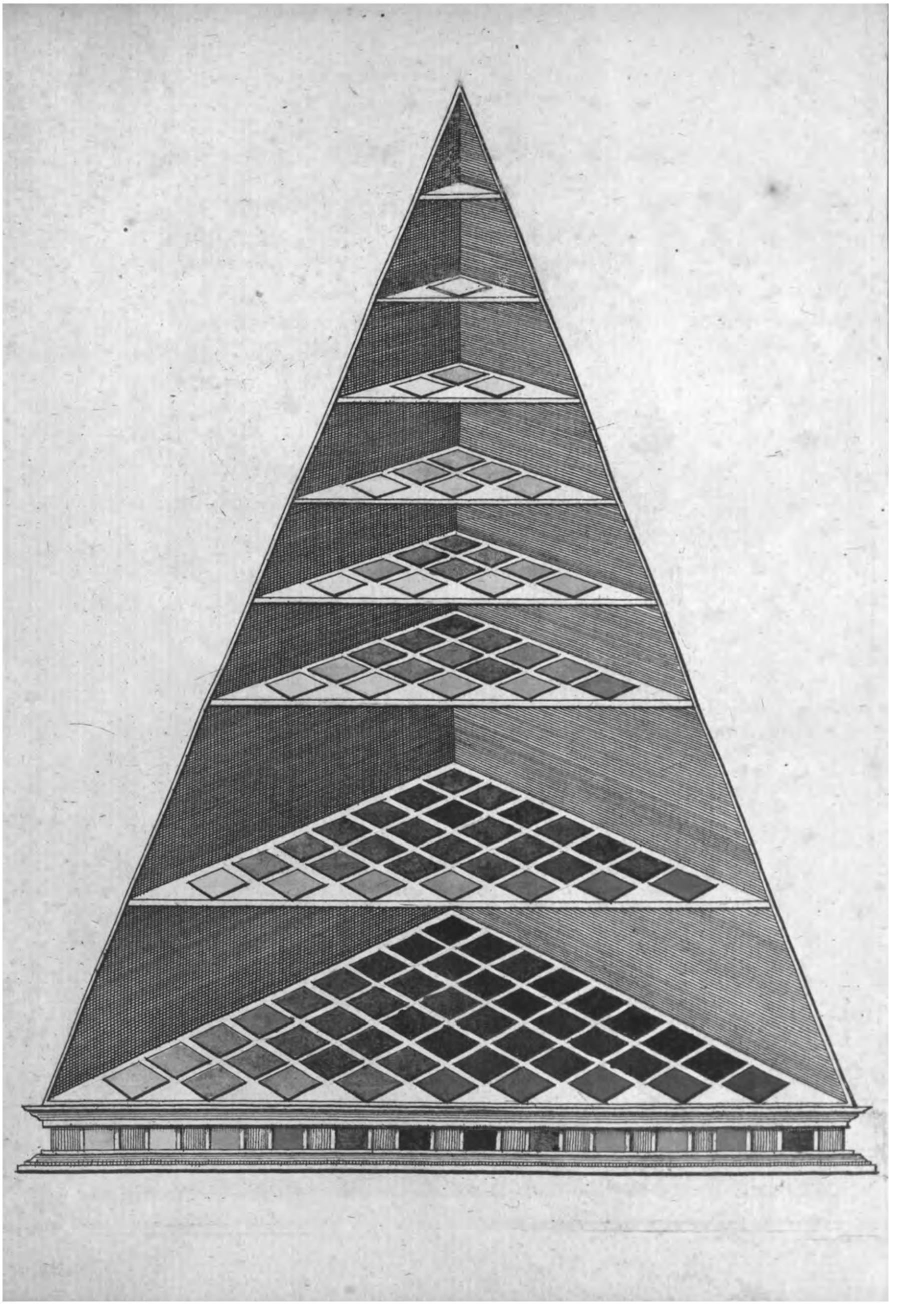
> «in the rainbow, but even more vividly in the rays of the sun when it passes through a triangular glass prism into an eclipsed room».[30]

While Mayer was a convinced Newtonian in mathematics and astronomy, he was a trichromatist regarding colours. And he was in good company. In 1771, the Jesuit Ignaz Schiffermüller claimed that his trichromatic system was «entirely founded in nature»[31] and its primaries could be admired more vividly in the rainbow and «in the sun's ray divided by a three-edged glass or prism».[32]

Trichromacy's universal validity was most strikingly exposed in *Farbenpyramide* (1772) (fig. 1/pl. 5) authored by Lambert with the help of the Prussian Court Painter Benjamin Calau. Here, Lambert explained that in the uppermost coloured triangle of their colourant-mixing scheme:

> «We have just resolved and separated light into its three basic colours, red, blue and yellow, from whose various mixtures the other, both prismatic colours and colourants, arise.»[33]

The statement explicitly merges, once more, colourants and spectral colours in one unique trichromatic phenomenon. Except for Le Blon, who was eager to keep colourants and spectral colours apart,[34] most 18th-century trichromatists accepted this thesis but none claimed spectral colours to be a means to define the three primaries.



1 Johann Heinrich Lambert and Benjamin Calau, *Farbenpyramide* (Coloured pyramid) in Johann Heinrich Lambert's *Beschreibung einer mit dem Calauschen Wachse ausgemalten Farbenpyramide*, 1772, etching on paper washed with carmine, gamboge and Prussian blue watercolours, 23 × 14 cm, Zurich, ETH-Bibliothek Rar 5100.

Considering the prismatic technology available in the 18th century, this ambiguity is not surprising. The spectrum presents a continuum of different hues, and nothing indicates that one is purer than another. Moreover, there was no available means to describe precise colour positions in the spectrum, such as the Fraunhofer lines would offer much later. Thus, whether a spectral red, for example, leant towards yellow or blue could only be judged by the eye and the spectrum could not have helped to pinpoint its pureness. Trichromatists' references to the spectrum were rather projections of the general trichromatic idea onto apparent colours.

‹True› and ‹Perfect› Primitive Red

These projections spurred attempts to visualise trichromacy with coloured diagrams. The central challenge was to identify the suitable colourants to use. The red one was particularly demanding as many colourants displaying this hue existed. In 1613, Aguilón looked for the «simplicem ruborem» in three red colourants and concluded that red lead was too yellowish, red lake too bluish, while vermilion showed a mid-tone that approached an «exquisita rubedinem».[35] In 1677, the physician Francis Glisson also chose vermilion over red lead to paint a red lightness scale.[36]

It is significant to note, however, that Aguilón and Glisson never looked for trichromatic mixtures but for right red hues. This configuration changed radically at the beginning of the 18th century when Le Blon developed a trichromatic printing process: Three mezzotint plates were each inked in blue, yellow and red; then printed on the same sheet to produce a full-colour palette.[37] To describe the genesis of this invention, Le Blon revealed that he had to find «les Couleurs primitives parfaittes parmy les Couleurs materielles».[38] His success was thus based primarily on the three main printing inks he developed. The final criterion for his primitive colours to be ‹perfect› lay in their ability to produce a set of secondaries and an indefinite number of tertiaries.[39] Le Blon's ‹perfect› red was neither vermilion nor another simple pigment but a transparent mixture of carmine and brazilwood, sometimes corrected with vermilion.[40]

A similar ‹pure› red was formulated in *Traité de Peinture au Pastel* (1708) and visualized in its second colour circle. The anonymous author of this short textbook subdivided red into two «rouges primitives»: vermilion and carmine, which produced the «vrai rouge» when mixed.[41] These two examples show that the 17th-century ‹simple› red evolved into ‹perfect› and ‹true› primitive red in the early 18th century. Its perfection was achieved by mixing colourants and its hue was no longer as deep as vermilion but rather more purplish.

Carmine and Magenta

The red technology of Le Blon and the anonymous author of *Traité de Peinture au Pastel* marked the beginning of a significant shift in the idea of ‹pure› red, which would exhibit a magenta/purple hue toward the end of the 18th century. A shift even more remarkable as such a colour was no longer to be found in Newton's spectrum and which came about when trichromacy was implemented through colourant mixing. Indeed, in the 1730s, the Jesuit Louis Bertrand Castel also produced «le vrai rouge» from a mixture of vermilion and carmine.[42] While Tobias Mayer opted again for vermilion, Georg Christoph Lichtenberg, who first published a coloured version of Mayer's diagram, stressed the problem of using that pigment in a trichromatic scheme.[43] In Lambert's *Farbenpyramide*, finally, vermilion disappeared from the main-red mixture and the shift from vermilion to carmine was completed.

Lambert wished to identify three unmixed colourants that were suitable to build a mixing chart because the general framework alone «had not yet determined which type of red, yellow and blue had actually to be used».[44] For red, Lambert and Calau chose carmine, a pigment made with American cochineal (*Dactylopius coccus)*, for the satisfactory secondaries it produced.

There is an enigmatic point in Lambert's text, though. Albeit pleased with the result, Lambert hypothesised that other colourants may be found eventually «that come even closer to the true prismatic primary colours».[45] This reference to the spectrum is highly surprising because the distinct magenta hue of carmine[46] does not appear in the spectrum at all. The spectral red, conversely, is much closer to vermilion as noted by the mineralogist Abraham Gottlob Werner.[47] There is no easy way to understand Lambert's reference to the spectrum, but there might be an explanation.

Before we come to that point, we shall first look at Goethe, who also embraced the shift to carmine slightly later and spoke more explicitly about it. He elaborated his long-standing interest in colours in an experimental series with the spectrum. His penchant for trichromacy emerges in *Beyträge zur Optik* (1791), where he found both pure yellow and blue among the prismatic colours, but not a pure red:

> «Among the actual coloured phenomena there are only two that give us a completely pure idea, namely yellow and blue. [...] On the other hand, we never know the red colour in a completely pure state: for we find that it leans either towards yellow or blue».[48]

In his *Farbenlehre* (1810), Goethe expanded on the subject and presented his six-part colour circle. He called the red colour in it purple *(Purpur)* or peach blossom *(Pfirsichblüt),* hereby stressing its purplish or magenta-like hue.

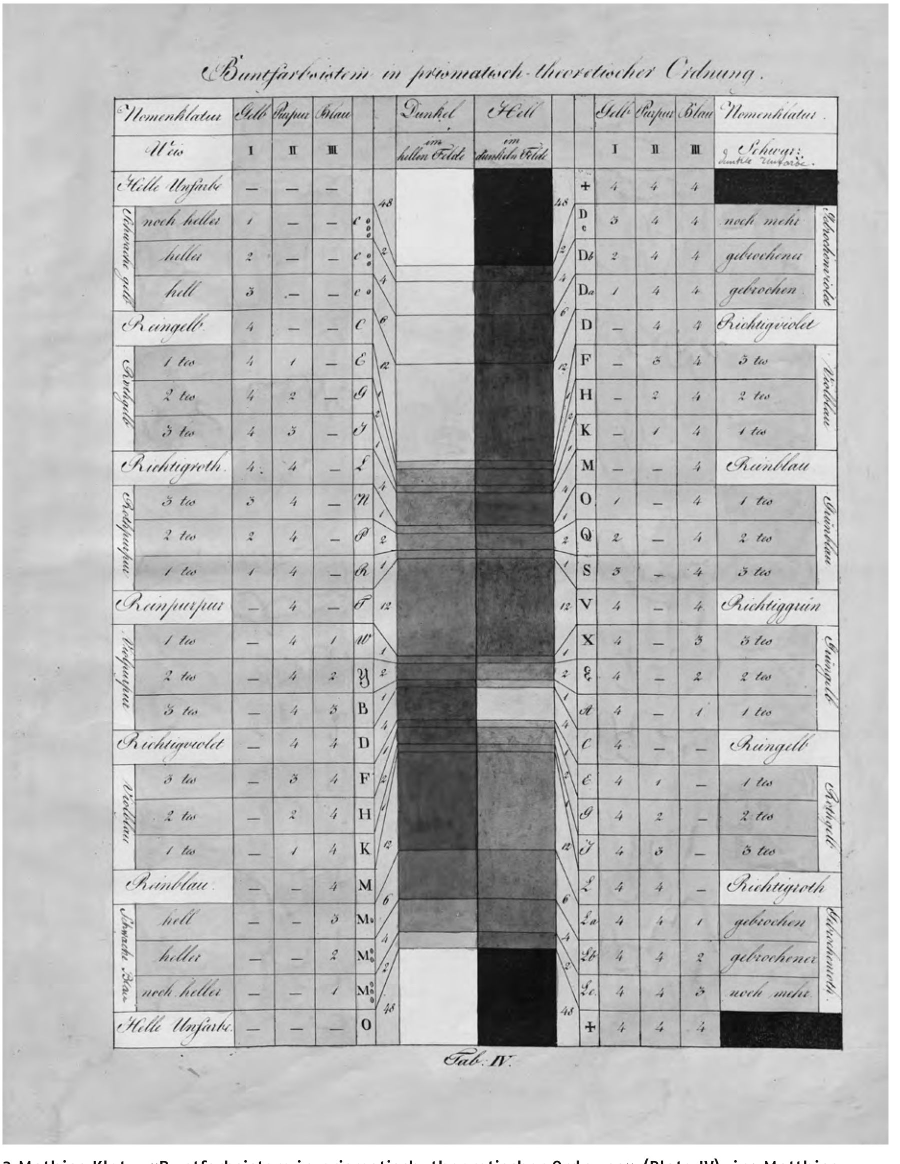
What is exciting here is how he identified ‹pure› red both with optical and material means. For the optical part, Goethe used the so-called inverted spectrum, produced by thorough inversion of light and shadow in the optical arrangement and showing the complementary colours to the ordinary spectrum. The central purple hue, which could also be produced by superposing the red and violet ends of the ordinary spectrum, is called magenta today and was named by Goethe ‹pure› red:

> «With this name, one should remove everything that could give to the red an impression of yellow or blue. We are to imagine an absolutely pure red, like perfect carmine dried on white porcelain.»[49]

Carmine was thus the colourant that Goethe associated with the magenta of the inverted spectrum. Along the same line the Bavarian court painter Mathias Klotz identified in his *Gründliche Farbenlehre* (1816) a «pure purple» *(Reinpurpur)* at the centre of the inverted spectrum and painted it with carmine (fig. 2/pl. 6).[50] Coming back to Lambert, we see that he also chose carmine as the primary red. Whether his selection of the primary red colourant was not only supported by colourant-mixing experiments but also by the observation of the inverted spectrum (without making that point explicit), we cannot tell yet. However, this hypothesis could explain Lambert's claim to have looked for his primary red in the spectrum. One thing is certain though: The shift from vermilion to carmine started with practitioners like Le Blon, who wanted to implement trichromacy, and was finalized in Lambert's work, who again aimed at practical goals with his trichromatic pyramid.

Conclusion

We have seen how historical sources spoke of ‹simple›, ‹pure›, ‹true› and ‹perfect› colours. While in the 17th century ‹simple› could be attributed to both a hue and an



2 Mathias Klotz, «Buntfarbsistem in prismatisch-theoretischer Ordnung» (Plate IV), in: Matthias Klotz, *Gründliche Farbenlehre; mit vier vom Verfasser selbst gemalten Tafeln…und zwey unfärbig gezeichneten zum Prismatisiren*, 1816, lithography on paper, washed with carmine, gamboge and Prussian blue watercolours and black ink, Munich, Bayerische Staatsbibliothek, Handschriftenabteilung, Lithogr. 206.

unmixed colourant, in the 18th century a ‹pure›, ‹true› and ‹perfect› colour almost exclusively referred to a specific hue, regardless by what means it was specifically produced (optical, a colourant or a mixture of several ones). The specificity of ‹pure›, ‹true› and ‹perfect› colours lay in a hue that did not verge or tend toward another. To these initial ‹sensorial› judgments made by expert eyes was subsequently added an additional and operational criterion when implementing trichromacy in the 18th century: ‹pure›, ‹true› or ‹perfect› colours became those that could practically fulfil the trichromatic promise of generating all other colours.

While these straightforward sensorial and operational meanings are sure, the metaphysical dimension of these adjectives remains unexplored. Authors like Aguilón, Castel, Lambert, Goethe, who had quite different ontological commitments, clearly emphasise chromatic pureness in the above sensorial and operational meanings rather than associating these abstract concepts with Platonic ideas or other essentialist or idealist attitudes. In sum, we are convinced that these authors shared a common understanding of why those colours should be called ‹pure›, ‹true› or ‹perfect›, an understanding that enabled unproblematic communication and provided the main reason to choose those terms.

Focusing on red as a case in point, we have shown how such adjectives in trichromacy were merged to other criteria and could, most importantly, be operationalized. In the 17th century, trichromacy had not yet been implemented and vermilion (perhaps for its similarity to the spectral red?) was regarded as primary. At the outset of the 18th century, Le Blon's printing experiments developed perfect red through mixing of several red colourants. With Lambert and Goethe, the status of pure red was assigned to a colourant and at the same time migrated out of the ordinary spectrum. And this was final. Carmine as the main red colour would appear in the trichromatic charts of James Sowerby (1809), Gaspard Grégoire (1812), Léonor Merimée (1814) and the aforementioned Klotz (1816). The reasons for this hue shift remain certainly complex, but we might highlight three important factors. First, attempts to implement trichromacy in practice intensified the search for the proper colourants during the Enlightenment. Second, carmine rose to a valid candidate during the 18th century, when new methods to produce this pigment from American cochineal were developed.[51] Third, the increasing awareness of the existence of the inverted spectrum enabled to visualise the magenta hue of carmine with optical means, too.

To conclude, we cannot resist adding a wider consideration on the identification of main red colour in the inverted spectrum. Trichromacy is used nowadays in CMYK colour printing. A quick glance unveils that the inks used here resemble the blue, yellow and red of the inverted spectrum. While we have shown how the idea of primary red shifted from vermilion to carmine, whether yellow and blue experienced a similar transition remains an open question. But we assume that there was again a close interplay between optical colour theory and practitioners' colourant mixing.

Notes

1 Ian Lawson, Pigments, Natural History and Primary Qualities: How Orange Became a Color, in: *Science in Color*, ed. Bettina Bock von Wülfingen, Berlin/Boston 2019, p. 136–146, here p. 144. François de Aguilón, *Opticorum libri sex: philosophiis juxtà ac mathematicis utiles*, Antwerp 1613, p. 41.

2 «Ein ‹reines Rot›, welche Farbe ist das? […] Welche Rot-vorstellung wird stillschweigend als verbindlich angenommen, wenn man von der Grundfarbe Rot spricht? […] das spektrale Rot oder das Purpurrot?» Eckart Heimendahl a. Carl Friedrich von Weizsäcker, *Licht und Farbe: Ordnung und Funktion der Farbwelt*, Berlin 1961, p. 78. If not otherwise specified, the translations are by the authors. Johann Wolfgang von Goethe, *Zur Farbenlehre*, 2 Vols., Tübingen 1810, Vol. 1, p. 298.

3 Michel Pastoureau, *Red: The History of a Color*, Princeton 2017, p. 116–123.

4 «Colour Orders, Colourants and Colour Terminology», website, 2021 https://techne.hypotheses.org/100 last accessed on 2 July 2021.

5 Rocco Sinisgalli, *Leon Battista Alberti: On Painting: a New Translation and Critical Edition*, Cambridge 2011, p. 31. See also Alan E. Shapiro, Artists' Colors and Newton's Colors, in: *Isis*, 1994, Vol. 85, No. 4, p. 600–630 and John Gage, *Colour and Culture. Practice and Meaning from Antiquity to Abstraction*, London 1994, p. 118–119.

6 Charles Parkhurst, Aguilonius' Optics and Rubens' Color, in: *Nederlands Kunsthistorisch Jaarboek*, 1961, Vol. 12, p. 35–49. Rolf G. Kuehni a. Andreas Schwarz, *Color Ordered. A Survey of Color Order Systems from Antiquity to the Present*, New York 2008, p. 40–45.

7 For this term see John Dixon Mollon, The Origins of Modern Colour Science, in: *Science of Colour*, ed. Steven K. Shevell, Washington 2003, p. 1–37, here p. 8.

8 Aguilón 1613 (as note 1), p. 29, 45. Joannes Marcus Marci, *Thaumantias. Liber de arcu coelesti deque colorum apparentium natura, ortu et causis*, Prague 1648, p. 124. Marin Cureau de la Chambre, *La lumiere*, Paris 1662, p. 7. See also Karin Leonhard, ‹The Various Natures of Middling Colours We May Learne of Painters›: Sir Kenelm Digby Looks at Rubens and Van Dyck, in: *Knowledge and Discernment in the Early Modern Arts*, ed. Sven Dupré a. Christine Göttler, London 2017 (Visual Culture in Early Modernity 60), p. 163–185, here p. 164.

9 See for instance Giambattista della Porta, *De refractione optices parte libri novem*, Napoli 1593, p. 197.

10 Aguilón exemplified trichromacy in optics with pigment mixing. Yet his «simplicium colorum species» were not «coloribus concretis» (i. e. colourants) but the hues they represented. Aguilón 1613 (as note 1), p. 38. See Parkhurst 1961 (as note 6), p. 42; Leonhard 2017 (as note 8), p. 167.

11 Robert Boyle, *Experiments and Considerations Touching Colours*, London 1664, p. 220. Francis Glisson, *Tractatus de ventriculo et intestinis*, Amsterdam 1677, p. 60.

12 Ulrike Kern, Samuel van Hoogstraeten and the Cartesian Rainbow Debate: Color and Optics in a Seventeenth-Century Treatise of Art Theory, in: *Simiolus: Netherlands Quarterly for the History of Art*, 2012, Vol. 36, No. 1/2, p. 103–114, here p. 103–104. Karin Leonhard, Verf, Kleur. Farbtheorie und Stilleben im 17. Jahrhundert, in: *Ad Fontes! Niederländische Kunst des 17. Jahrhunderts in Quellen*, ed. Karin Leonhard, Claudia Fritzsche, a. Gregor J. M. Weber, Petersberg 2013, p. 55–82, here p. 70.

13 Ulrike Boskamp, *Primärfarben und Farbharmonie. Farbe in der französischen Naturwissenschaft, Kunstliteratur und Malerei des 18. Jahrhunderts*, Weimar 2009, p. 152–154.

14 See note 10 and Gabor Á. Zemplén, *The history of vision, colour, & light theories: introductions, texts, problems* (Bern studies in the history and philosophy of science / Educational materials 5), Bern 2005, p. 207.

15 Willem Beurs, *De Groote Waereld in 't Kleen* Geschildert, Amsterdam 1692, p. 4.

16 Tobias Mayer, Bericht über Mayers Vortrag auf der Societätsversammlung, *Göttingische Anzeigen von gelehrten Sachen;* 1758, No. 2, p. 1385–1389, here p. 1388. Ignaz Schiffermüller, *Versuch Eines Farbensystems*, Vienna 1771, p. 8.

17 Edme Mariotte, *De la Nature des couleurs*, Paris 1681, p. 525–526.

18 Moses Harris, *An Exposition of English Insects*, London 1776, p. v.

19 Moses Harris, *The Natural System of Colours […] Arising from the Three Primitives, Red, Blue, and Yellow*, London 1781, p. 3. See also Pastoureau 2017 (as note 3), p. 132.

20 Anonymous, Traité de la Peinture au Pastel, avec la Maniére de Composer les Pastels, in: *Traité de la Peinture en Mignature*, The Hague 1708, p. 149–174, here p. 152. Jacob Christoff Le Blon, *Coloritto; or the harmony of colouring in painting*, London 1725, p. 7. Louis Bertrand Castel, *L'Optique des Couleurs*, Paris 1740, p. 106.

21 Filippo Mocenigo, *Universales Institutiones ad Hominum Perfectionem*,Venice 1581, p. 305. Aguilón 1613 (as note 1), p. 39. Johannes Zahn, *Oculus artificialis teledioptricus*, Würzburg 1685, p. 111. «Colores simplices seu primitivos» Tobias Mayer and Georg Christoph Lichtenberg, *Tobiae Mayeri, …Opera Inedita I*, Göttingen 1775, p. 33.

22 Julia A. DeLancey, ‹In the Streets Where They Sell Colors›: Placing ‹Vendecolori› in the

Urban Fabric of Early Modern Venice, in: *Wallraf-Richartz-Jahrbuch,* 2011, Vol. 72, p. 193–232, here p. 195–196.

23 Johann Scheffer, *Graphice Id Est, De Arte Pingendi,* Nuremberg 1669, p. 158–169.

24 «Hooftverwen, of hooft-stoffen der olyverwen». Beurs 1692 (as note 15), p. 4 and p. 6–7.

25 Boskamp 2009 (as note 13), p. 110–112.

26 On purple and violet see Martin Kemp, *The Science of Art: Optical Themes in Western Art from Brunelleschi to Seurat,* New Haven 1990, p. 282. Orange is deemed a secondary more often in optical treatises, while painters obtained orange directly from unmixed pigments. See Lawson 2019 (as note 1), p. 144–145 and Rosamond Drusilla Harley, *Artists' Pigments c. 1600–1835: A Study in English Documentary Sources,* 2nd ed., London 2001 (Technical Studies in the Arts, Archaeology and Architecture), p. 125.

27 Marin Mersenne, *Harmonie universelle, contenant la théorie et la pratique de la musique,* Paris 1636, p. 212. Athanasius Kircher, *Ars magna lucis et umbrae,* Rome 1646, p. 76.

28 Isaac Newton, A letter of Mr. Isaac Newton, Professor of the Mathematicks in the University of Cambridge; containing his new theory about light and colors..., in: *Philosophical Transactions,* 1671/72, Vol. 6, No. 80, p. 3075–3087, here p. 3082.

29 Shapiro 1994 (as note 5).

30 «Man siehet sie im Regenbogen; noch lebhafter aber in den Strahlen der Sonne, wenn er durch ein dreyeckiges gläsernes Prisma im ein verfinstertes Zimmer fället» Göttingen, Universitätsbibliothek, MS T. Mayer 15, 12, fol. 1v–2r.

31 «ganz in der Natur gegründet», Schiffermüller 1771 (as note 16), p. 6.

32 «in dem durch ein dreyschneidigtes Glas oder Prisma getheilten Sonnenstrale», Schiffermüller 1771 (as note 16), p. 8.

33 «[...] haben wir eben das Licht in seine drey Grundfarben, roth, Blau, Gelb aufgelößt und abgesondert, aus deren verschiedenen Mischung die übrigen sowohl prismatischen als Malerfarben entspringen.» Johann Heinrich Lambert, *Beschreibung einer mit dem Calauschen Wachse ausgemalten Farbenpyramide,* Berlin 1772, p. 82.

34 Katie Scott, *Becoming Property: Art, Theory, and Law in Early Modern France,* New Haven 2018, p. 260. Ad Stijnman, *Jacob Christoff Le Blon and Trichromatic Printing,* ed. Simon Turner, Ouderkerk aan den Ijssel 2021 (The New Hollstein Dutch & Flemish Etchings, Engravings and Woodcuts 1450–1700), p. lxxxvii–lxxxxviii.

35 Aguilón 1613 (as note 1), p. 41. See the translation in Lawson 2019 (as note 1), p. 144.

36 Glisson 1677 (as note 11), p. 66. See also Rolf G. Kuehni and Ralph Stanziola, Francis Glisson's Color Specification System of 1677, in: *Color Research & Application,* 2002, Vol. 27, No. 1, p. 15–19.

37 Stijnman 2021 (as note 34), p. xlvii–lxxxiii.

38 British Museum, Add. Ms. 4299, fol. 75. For the translation see Otto M. Lilien, *Jacob Christoph Le Blon 1667–1741: Inventor of Three- and Four Colour Printing,* Stuttgart 1985 (Bibliothek des Buchwesens 9), p. 30.

39 This infomation is given in Pierre des Maizeaux, *Lettre ecrite de Londres par M. Des-Maiseaux, ... touchant l'Art d'imprimer des Tableaux & des Portraits en couleur,* in: *Journal des Sçavans,* 1722, Vol. 18 May, p. 316–318, here p. 317.

40 Stijnman 2021 (as note 34), p. lxxvi.

41 Anonymous 1708 (as note 20), p. 152–153.

42 Castel 1740 (as note 20), p. 113–114.

43 Mayer/Lichtenberg 1775 (as note 21), p. 96 a. 99.

44 «Damit ist nun aber noch nicht bestimmt, welche Art von Roth, Gelb und Blau eigentlich genommen werden müße», Lambert 1772 (as note 33), p. 22.

45 «die den wahren prismatischen Grundfarben noch näher kommen», Lambert 1772 (as note 33), p. 58.

46 Jo Kirby, Marika Spring, and Catherine Higgit, The Technology of Eighteenth- and Nineteenth-Century Red Lake Pigments, in: *National Gallery Technical Bulletin,* 2007, Vol. 29, pp. 69–96. Here p. 73.

47 Abraham Gottlob Werner, *Von den äußerlichen Kennzeichen der Foßilien,* Leipzig 1774, p. 121.

48 «Unter den eigentlich farbigen Erscheinungen sind nur zwey die uns einen ganz reinen Begriff geben, nämlich gelb und blau. […] Dagegen kennen wir die rothe Farbe nie in einem ganz reinen Zustande: denn wir finden daß sie sich entweder zum Gelben oder zum Blauen hinneigt.» Johann Wolfgang Goethe, *Beyträge Zur Optik,* Weimar 1791, p. 30–31.

49 «Man entferne bey dieser Benennung alles, was im Rothen einen Eindruck von Gelb oder Blau machen könnte. Man denke sich ein ganz reines Roth, einen vollkommenen, auf einer weißen Porzellanschale aufgetrockneten Carmin.» (Goethe 1810 [as note 2], p. 297–298).

50 Mathias Klotz, *Gründliche Farbenlehre; mit vier vom Verfasser selbst gemalten Tafeln... und zwey unfärbig gezeichneten zum Prismatisiren.* München 1816, p. 5 and 11. We cannot discuss here in full his idiosyncratic colour terminology.

51 Kirby et al. 2007 (as note 46), p. 71.