Color Theory in Medieval Islamic Lapidaries: Nīshābūrī, Tūsī and Kāshānī

Eric Kirchner* and Mohammad Bagheri†

Abstract. This paper discusses descriptions of color theory in a series of lapidaries by Nīshābūrī, Tūsī and Kāshānī, written in 1196, ca. 1258 and in 1300, respectively. The texts are almost identical and seem to originate from Nīshābūrī. They describe a color theory that deviates from the Aristotelian account in several ways. They represent one of the first instances in which it is stated explicitly that by mixing black and white, grey is produced. This contradicts the Aristotelian dogma that such mixtures may produce all other colors. The texts are the first to refer explicitly to a hue scale, recognizing that by mixing blue and yellow in different proportions, colors are produced that change gradually from blue, via green, to yellow. Only tonal scales, obtained by mixing a color pigment with black or white, had been described before.

In spite of the description of a hue scale in this text and tonal scales in another text by Tūsī, it is shown that the authors of these texts did not yet distinguish between differences in lightness and differences in hue.

Keywords. Color, Grosseteste, Ibn Sīnā, Kāshānī, Nīshābūrī, optics, Tūsī

1. Introduction

It is now well established that during the golden age of Islam there were important developments in optics (Lindberg, 1976; Sabra, 1991; Rashed, 1993). Much less, however, is known about the developments of the related discipline of color theory during the same period. Most overviews are several decades old.[1] This is probably due to the lack of new material found about developments in color theory during the Medieval period of Islam. There is only one recent work reporting new material (Adamson, 2006). In this article, we present a new *locus* that escaped investigations up to now. It sheds more light on the development of color theory in Persia at the end of the 12th and during the 13th century.

This article is organized by first providing a brief summary of the developments in color theory, with an emphasis on those aspects addressed by the newly (re-)discovered material. This is followed by a textual analysis of the fragments presented here. After

*Wollegras 14, 2318 TG Leiden, The Netherlands. E-mail: ekirchnr@xs4all.nl, herihor@yahoo.com
†History of Science Institute, University of Tehran, P.O. Box 13145-1785, Tehran, Iran. E-mail: mohammad.bagheri2006@gmail.com

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giving an English translation and analysis of the texts, we discuss the material in the context of the history of color theory.

2. *Early Developments in the Theory of Color Mixing*

The first coherent explanation of color was given by Aristotle in Book III of the *Meteorologica* (Lee, 1962, pp. 240–246). In an explanation of rainbow formation, Aristotle argued that colors are produced by different combinations of darkness and lightness. Excellent summaries of Aristotle's analysis of color have been published before (Shapiro, 1994, pp. 602–603; Lettinck, 1999, pp. 243–246). Here, we only have room to mention two conclusions from his work that are particularly important for the present article:

(i) All colors can be ordered in a linear series from white to black. This series is described in *De sensu* 4, 442a20–25, and is represented here in Figure 1 (Hett, 1936a, p. 245). This series may have been meant to be essentially an ordering of colors according to their lightness (Kuehni and Schwarz, 2008, pp. 28 and 31). But its order does not agree with the order of the rainbow colors. Therefore, when describing the rainbow in the *Meteorologica,* Aristotle had to change the series slightly: blue is not mentioned, yellow is not considered to be a real color but just a visual illusion due to contrast and violet and leek-green have changed position (Gage, 1993, p. 13).

(ii) By mixing white and black, all other colors can be produced.

The first conclusion implies, when restated in modern terminology, a one-dimensional color space. Modern science has shown that color is an essentially three-dimensional phenomenon (Kuehni and Schwarz, 2008, p. 70).

These conclusions were based mostly on an analysis of the rainbow colors and therefore relate to the mixing of light. However, later scholars assumed that Aristotle's conclusions were valid for mixing pigments as well. Aristotle had already hinted at a link between the production of rainbow colors and producing colors by mixing pigments. In his discussion of rainbow colors he wrote about the colors red, green and violet/purple that he recognized in the rainbow: 'These are almost the same colors which the painters cannot manufacture; for there are colors which they create by mixing, but no mixing will give red, green or violet/purple.'[2]

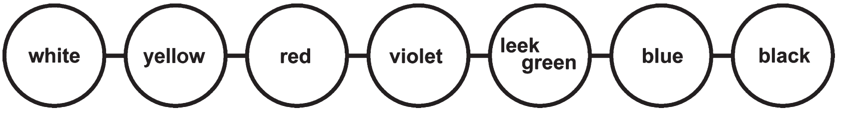

Fig. 1. Color ordering according to Aristotle in *De sensu* (reconstruction). This ordering obviously confuses changes in color tones (hues) and changes in lightness.

It would take until the 19th century before it was realized that when lights of different colors are mixed, other colors are produced than when pigments of different colors are mixed (Shapiro, 1994, p. 602n5; Kuehni and Schwarz, 2008, pp. 16 and 19).

Both conclusions from Aristotle were generally accepted by ancient scholars. According to Theophrastus (d. 287 B.C.), all philosophers had agreed on this opinion (Stratton, 1917, p. 137; Struycken, 2001, p. 110, 2003, p. 279). Ptolemy, in the 2nd century, agreed that all colors can be produced by mixing white and black (Smith, 1996, p. 27). The same conclusion was also supported by Alexander of Aphrodisias (ca. AD 200) in his treatise on color and in his discussion of Aristotle's *Meteorologica* (Gätje, 1966, p. 269, 1967b, p. 373; Sharples, 1992, p. 23).

In the Islamic era, Job of Edessa (d. ca. 835) supported the Aristotelian view on color (Winter, 1954, p. 194). When commenting on the works of Aristotle and Alexander of Aphrodisias, Ibn Suwār ibn al-Khammār (d. 1030) also supported it by presenting evidence from observations. He wrote that if very black coal is burnt, its blackness makes the fire look more greenish—which from a modern perspective was possibly due to traces of metal in the coal (Lettinck, 1999, pp. 351 and 357). Also the great commentator Ibn Rushd (d. 1198) agreed with the Aristotelian view that the range of colors is caused by combinations of brightness and darkness in varying proportions (Boyer, 1987, p. 84).

But there were also slight variations to the Aristotelian dogma that all colors can be produced by mixing black and white. Democritus (460 to 370 B.C.) and Empedocles (490 to 430 B.C.) added red and yellow as third and fourth elementary colors next to black and white.[3] They claimed that with these four elementary colors all other colors can be produced (Gage, 1993, p. 12). In a similar way, Alī ibn Rabbān al-Tabarī (d. 855) stated that white, black and red are the fundamental colors and that all other colors can be derived from them (Morabia, 1991, p. 701).

The first true break with the Aristotelian view of color ordering is found with Ibn Sīnā (d. 1037). In his *Kitāb al-Shifā'* (later translated into Latin as *Liber de Anima*, abbreviated as *DA* in the translation below) the whole of Chapter 4 in section 3 is devoted to colors.[4] There we read:

> Moreover, if whiteness does not exist without light and blackness not in ways already discussed, then whiteness and blackness cannot only be joined in one manner. A manifestation of this is the fact that white gradually passes to black by three paths. The first is via pale (*DA*: light yellow-green) and its progression is pure: it will indeed be of pure progression, at first it progresses to pale (*DA*: light yellow-green), from there to grey (*DA*: yellow-green), and continuing in this manner until black is obtained, because thus proceeding to its limit, it does not veer from gradually stretching towards blackness, until it becomes pure black. There is also another path proceeding [from whiteness] toward red (*DA*: light red), and from there to red brown (*DA*: red), thereafter to black. The third path is the one going to green (*DA*: blue-greenness), from there to indigo, thereafter to blackness. And in these ways not all color diversity can exist, neither can they be the source of the diversity of [Aristotelian] median colors. (translation from Kuehni and Schwarz, 2008, p. 34; cf. Bakos, 1956, vol. 2: p. 78)

This shows that Ibn Sīnā rejected the second Aristotelian conclusion mentioned above that all 'intermediate colors' can be produced by mixing black and white. But is also

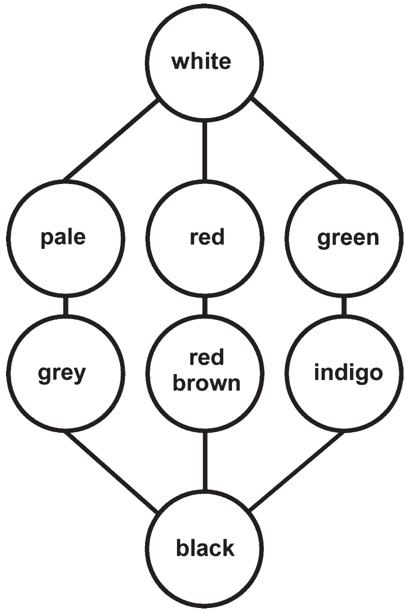

Fig. 2. Color ordering according to Ibn Sīnā in *Kitāb al-Shifā'* (reconstruction).

clear that Ibn Sīnā did not agree with the first Aristotelian conclusion either. The color ordering proposed by Ibn Sīnā is necessarily a two dimensional one, as illustrated in Figure 2 (Morabia, 1991, p. 703). After 1244 Ibn Sīnā's new system of color ordering became well known in Europe through its discussion by Vincent de Beauvais in the *Speculum majus* (Kuehni and Schwarz, 2008, p. 34).

In Europe, the Benedictine monk and highly skilled practicing metal worker Theophilus (ca. 1120) mentioned briefly that for each color range, mixing a color pigment with white or with black produces up to 12 different scales.[5] In the Islamic world, Ibn Sīnā's new color order was elaborated further by the director of the astronomical observatory in Maragha, Nasīr al-Dīn al-Tūsī (d. 1274). In an answer to questions about Ibn Sīnā's color theory raised by one of his staff members, Najm al-Dīn al-Kātibī, Tūsī wrote[6]:

> Regarding the production of colors from black and white there are numerous paths, from which one gradually walks from white to black. The path through yellow belongs there: First by the mixing of dense and fire, both in small amount, the straw-yellow is produced, then the lemon-yellow, then the saffron-yellow, then the orange-yellow, then the grenade-yellow, then in it the tendency towards black increases, according to the increase in the number of dense particles and the decrease of fire, until it becomes black. Another path goes through red. First it becomes rosy[7] then like evening-red, then blood-colored, then purple, then violet, violet-colored. One path goes through green. It becomes pistachio-colored, then leek-colored, then verdigris-colored, then eggplant-colored (*bādinjānī*), then naphta-colored. One path goes through blue. It becomes

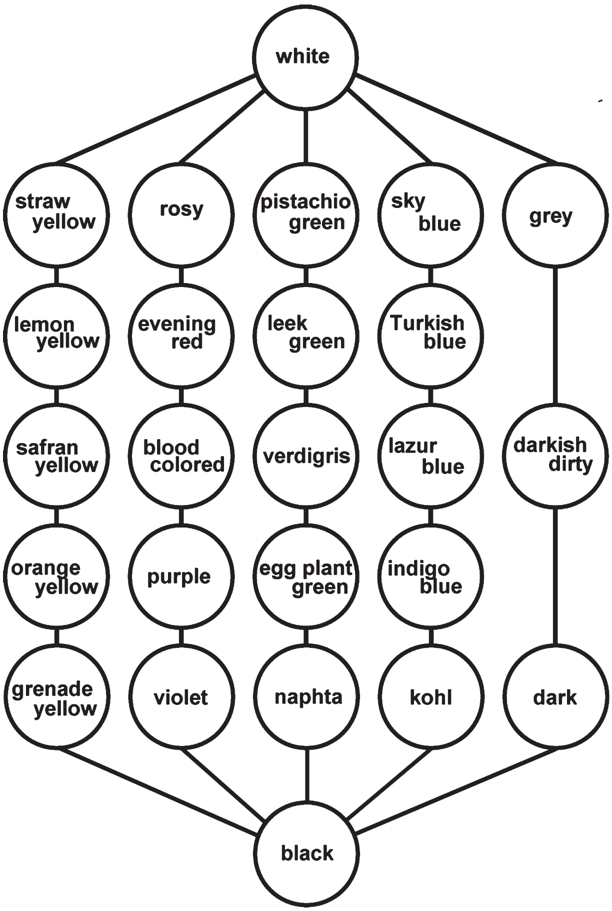

Fig. 3. Color ordering according to Tūsī in his answer to al-Kātibī (reconstruction).

> sky-blue, then Turkish blue, then lazur blue (*lāzwardī*), then indigo blue, then like kohl. One path goes through turbidity/dirt. It becomes grey, then darkish/dirt-colored, then dark etc.
>
> These all occur according to the differences of particles in transparency, opacity (density), light and darkness. Now and then one sees a color together with another, and a different color is produced, such as green from yellow and blue, verdigris from green and white. There are infinitely many of such arrangements, and some are often found in small particles of plants and animals. Anyone who observes them is surprised by their number. (Wiedemann, 1908, p. 90)

So instead of the three paths leading from white to black, as described by Ibn Sīnā, Tūsī found that there are no less than five such paths. They pass through yellow, red, green, blue and grey (Wiedemann, 1908). Thus, a new color ordering results that can be illustrated as in Figure 3.

3. Background of the Texts

The newly (re-)discovered discussions on color theory were written by three Persian authors. The texts are in Persian, and as far as we know they have never been translated into a Western language before. We could only find two brief references, by Nasr and by Porter, to the color theories that are developed in these texts (Nasr, 1970, p. 511; Porter, 1994, pp. 70–71).

The first author is Muhammad ibn Abī al-Barakāt al-Jawāharī al-Nīshābūrī, a jewel-maker and expert on precious stones. His work *Jawāhir Nāmeh-i Nizāmī* ('The book of stones for Nizām') was written in 1195–1196 (Porter, 2008, pp. 609–610). It deals with minerals, metals and stones, and color obviously plays an important role in characterizing them. The majority of the work was original and apparently based mostly on the author's experience. At some places it shows influences from a well known lapidary from al-Bīrunī, entitled *Kitāb al-jamāhir fi ma'rrifat al jawāhir*—'The book of the multitude of knowledge of precious stones' (Krenkov, 1936; al-Hādī, 1995), but this is not the case for the paragraphs related to color theory. Although there are many other lapidaries known from the Medieval Islamic world, both in Arabic and in Persian, they seem to be unrelated to the texts that we investigate here.[8]

Nīshābūrī's work was an inspiration for several later lapidaries, such as the *Tansūkh-nāme-yi Ilkhānī* ī ('The book on precious stones for the Ilkhan'). It was completed ca. 1258 and its author is Nasīr al-Dīn al-Tūsī, the famous scholar whose other work related to color we already discussed (Porter, 2008, p. 610). Tūsī copied large parts of Nīshābūrī's text, including the whole of Book I, only slightly modifying it at certain places. At other places whole new chapters were inserted.

Finally, the last member of this series of lapidaries was written by the famous historian Abū'l-Qasim 'Abd Allāh Kāshānī' (Afshār, 2000, pp. 145 and 160). It was written in 1300 (Vesel, 2000). Under the name '*Arāyes al-Jawāhir wa nafāyes al-atāyeb*' ('Brides of jewels and gems of delicacies'), again parts of Nīshābūrī's text were largely copied, including its first chapter that contains the description of color theory. At other places in the book, Kāshānī inserted original texts, such as an original description of ceramics that became the most well-known text on this topic in the entire Islamic world (Porter, 2008, p. 610).

For the Persian texts the reader is referred to the editions indicated above.

4. Translation of the Texts

An edition of Nīshābūrī's text was recently published (Afshār, 2004, pp. 69–70). Critical editions were published for Tūsī's text (Razavī, 1969, pp. 23–25) and Kāshānī's text (Afshār, 1966, pp. 21–22) as well. The translations below are based on these editions.

Nīshābūrī	Tūsī	Kāshānī
On the Causes of Substances' Colors	On the Causes of Substances' Colors	On the Causes of Substances' Colors
All colors are white at the beginning, and black at the end. And all colors are located in between white and black; thus white moves gradually toward black until it becomes black, which is the opposite extreme color for white, and	All colors are white at the beginning, and black at the end[A]. And all colors are located in between white and black; thus white moves toward black until[B] it becomes black, which is the opposite extreme color for white.	All colors are white at the beginning, and black at the end. And the rest of the colors are located in between white and black. White moves gradually toward black, until it become black, which is its opposite extreme.
Different colors are produced by mixing white and black, and every color in turn will create a specific color, mixing with any particular color.	Different colors are produced by mixing white and black, and every color in turn will create a specific color when mixing with any other specific color.	Different colors are produced by mixing white and black.
And in every color, there are two extremes: the lightest point and the darkest point.	In every color, there are two extremes: the lightest point and the darkest point.	And in every color, there are two extremes: the lightest point and the darkest point.
If yellow, for instance, is mixed with blue, it will result in green (and the green color is an attribute which stands between those two extremes) and excess and wastage are in its both sides; and all other colors have the same situation (and between these two extremes, there are various green tones which differ from each other in greenness.)[I] Among all the colors, it is the green color that contains big differences in greenness among the variants, such as cyan, turquoise, dark green, viridian and so on. If one of these variations is mixed with other color which is not green, a new color is produced; and since this variation is accurate, the color diversity is unrestricted; and the cause is clear.	If yellow, for instance, is mixed with blue, it will result in green. Therefore, green possesses two extremes, like other colors; and between these two extremes, there are various green tones[C] which differ from each other in greenness, such as[D] cyan, turquoise, dark green (and viridian) and so on. Since this variation is accurate, the color diversity is unrestricted.	If yellow, for instance, is mixed with blue, it will result in green, which is located between two extremes. And there are various green tones which differ from each other in greenness, such as cyan, turquoise, dark green (and viridian) and so on. If one of these variations is mixed with another color, a new color is produced; and since this variation is accurate, the color diversity is unrestricted.

Nīshābūrī	Tūsī	Kāshānī
The color differentiation of some substances lies in the integration of the soil with wet, which intermixes with the stone's substance, as various colors can be observed, for instance, in a small portion of a stone, and it is reasonable to assume it to contain different layers. Every layer of wetness mixture possesses a specific color to reach the substance of that stone. If there is only one kind of category, it necessitates one color; if there are two kinds of categories, they necessitate two colors; if three categories, three colors, etcetera.	The color differentiation of some substances lies in the integration of the substance with soil, which intermixes with the stones. Therefore, various colors can be observed, for instance, in a small portion of a stone. A stone[E] consists of different layers, and every layer possesses a specific color.	And the color differentiation of some substances lies in the integration of the substance with soil, which intermixes with the stones. Therefore, various colors can be observed, for instance, in a small portion of a stone.
If, for some reasons, a stone is deprived of sun light for a long time, its components' discrete will become so weak and low that moisture penetrates in them, until it surrounds the stone completely.	If, for some reasons, a stone is deprived of sun light[F] for a long time, its components will become so weak that moisture penetrates in them until[B] it surrounds the stone completely.	If, for some reasons, a stone is deprived of sun light for a long time, its components will become so weak that moisture penetrates in them until it turns into clay.
After that, if, for some other reasons, the stone becomes warm for a long time, and so intensely that the hot weather is absorbed in the stone, the moisture will be dried out. And various absorbing[J] parti-colored clays, and so on, will be produced. And every stone which is built up of that colored clay (that is the main substance) possesses the same features and colors sensibly and tangibly, such as red, absorbing[J] white, blue, black, and so on.	After that, if, for some other reasons, the stone becomes warm for a long time, and so intensely that the hot weather is absorbed in the stone, the moisture will be dried out. Therefore, various parti-colored clays will be produced; and every stone which is built up of that clay (that is the main substance) possesses the same features and colors sensibly and tangibly, such as red, white, yellow, blue, black, and so on.	After that, if, for some other reasons, the warm weather surrounds the stone and absorbs the stone's moisture, various parti-colored clays will be produced, such as red, white, blue, black, and so on.

Nīshābūrī	Tūsī	Kāshānī
When these clays are dried and become solid by the sun's heat, the clay decomposes into discrete components; from every component and layer of the clay will emerge a soil with a specific color. Whenever these colored soils are mixed with different soils, a new color will appear.	When these clays are dried and become solid by the sun's heat, the clay decomposes into discrete components; from every component and layer of the clay will emerge a soil with a specific color. Whenever these colored soils are mixed with different soils, a new color will result.	After that, when these clays are dried and become solid by the sun's heat, the clay decomposes into discrete components; and whenever these colored soils are mixed with different soils, a new color will result.
For example, if yellow soil is mixed with blue soil, based on the quantity of each soil, a new color will be produced, which is green.	For example, if yellow soil is mixed with blue soil, based on the quantity of each soil, a new color will be produced, which is green.	For example, if yellow soil is mixed with blue soil, a new color will be produced, which is a special green.
If yellow color exceeds the blue one, the third color will be a light green; and if blue is greater than yellow in quantity, the resulting color will be a dark green.	If yellow color exceeds the blue one, the third color will be a light green[G]; and if blue is greater than yellow in quantity, the resulting color will be a dark green[H].	And if yellow color exceeds the blue one, the third color will be a light green. And if blue is greater than yellow in quantity, the resulting color will be a dark green.
Similarly, if white color and black color are mixed with each other, grey will result.	Similarly, if white color and black color are mixed with each other, an incense-grey color will result.	Similarly, if white and black are mixed with each other, a grey smoky color will result,
(God, who is great and aware, possesses the whole knowledge).	(God possesses the whole knowledge).	God possesses the whole knowledge.

5. Remarks about the Translations

The translations show that generally all three authors' texts are very similar.

More specific remarks are indicated by superscripts. For reasons of clarity, remarks A–H are indicated only in the translation of Tūsī's text, but obviously also apply for the other two texts for those cases in which the text fragments are identical. Remarks I and J apply only to Nīshābūrī's text.

[A]This sentence may be understood as 'colours all emanate from the mixture of white and black in different proportions; white is the origin and black the end result of colours.' (Porter, 1994, p. 70)

[B]The word for 'until' that is used here has more emphasis in the Persian text. A more literal but less fluent translation would be 'to the extent that.'

[C]We note that the Persian word used for '(color) tone' is also the word for 'shade.'

[D]Literally, the colors are named as follows: 'cyan' is *fustuqī* (lit. pistachio), 'turquoise' is *zumurrudī* (lit. emerald), 'verdigris' is *zangārī* (lit. green rust, i.e. cyan-blue) and 'viridian' is *naftī* (lit. naphtha).

[E]The word 'stone' mentioned here does not refer to stones in general, but to a special variety called *jazā'*. It has a black color with white, yellow and red points on it. The *jazā'*-stone is found in agate mines.

[F]Literally, the text says 'sun beam'.

[G]The Persian expression used here for light green is *sabz-e roshan*.

[H]The Persian expression used here for dark green is *sabz-e tīreh.*

[I]In the manuscript, the text fragment indicated here between square brackets is given in a footnote.

[J]The literal translation of this word is 'edible'.

6. The Role of Black and White

In the translated text fragments, it is written that 'all colors are located in between white and black.' The word 'located' refers to a position in what modern science would refer to as a color space. It is not surprising that Tūsī places colors between black and white—in fact, we already saw that this had been the dominant point of view since Aristotle.

But what is striking in this text fragment is that although it is stated that all colors are located between black and white, it is *not* concluded that all colors can thus be produced by mixing black and white. This had been the undisputed conclusion since the days of Aristotle. But in this text, it is stated that 'if white color and black color are mixed with each other, an incense-grey color will result.'

Only two earlier texts are known that make a similar statement about mixing black and white to produce grey. In the peripatetic *De Coloribus*, dating from the 4th/3rd century BCE, it is stated that

> The other colours derived from these by mixture in greater or smaller proportions make many different varieties. By greater and smaller proportions I mean such as red and purple, by mixture such as white and black, which when mixed give an appearance of grey. So when what is black and shady is mixed with light the result is red (792a-b) (Loveday *et al*., 1913; Hett, 1936b, p. 9).

When comparing these confusing statements by pseudo-Aristotle with the texts of Nīshābūrī, Tūsī and Kāshānī, the latter authors are remarkably clear.

The only other earlier mention of the fact that mixing black and white produces grey is by Theophilus. In Book I, Chapter VI of *De Diversis Artibus* he writes: ‘Then mix black with a little white; this color is called dark grey [*veneda*]’ (Dodwell, 1986, p. 7). Thus we see that the formulations by Theophilus (ca. 1120) and Nīshābūrī (1196) agree very well.

Nīshābūrī’s statement about black and white producing grey is not consistent with another statement in the same text fragment: ‘Different colors are produced by mixing white and black and every color in turn will create a specific color when mixing with any other specific color.’ It is not clear what is meant by the first half of this sentence. If the ‘different colors’ refer only to different shades of grey, this line of text would be consistent with the other line of text already mentioned. But it seems to be more probable that the ‘different colors’ in this text refer to chromatic colors. In that case, the text is not internally consistent and represents an intermediate position between the Aristotelian and the modern point of view. Another option to make the text consistent would be to reconsider the translation of the other line of text: ‘if white color and black color are mixed with each other, an incense-grey color will result.’ If here, the incense-grey color is mentioned as just one of several colors that may be produced when mixing black and white, then the text would be consistent. However, such an interpretation of the text does not seem probable. Such uncertainty is not apparent in the Persian text. And exactly the same grammatical construction and formulation is used in the preceding lines when mixing blue and yellow is described. In those lines, extending the semantic range to indicate uncertainty about the color being produced seems to be unlikely.

The insight that white and black are fundamentally different from the chromatic colors and cannot generate them, is currently considered to be one of the most radical of the Renaissance revisions of the concept of color and a starting point for Newton’s optical work (Shapiro, 1994, p. 601). Before Newton, 13 authors had already discovered this fact (Shapiro, 1994, p. 628). The first was Theodoric of Freiberg, ca. 1305, stating that by mixing black and white, ‘the middle colors are not produced by that method.’ But Theodoric of Freiberg remained vague about what mixing black and white did produce: ‘a mixture of white and black . . . does not produce anything except a remission of the white and black from their perfections’ (Würschmidt, 1914, pp. 66–67; Parkhurst, 1987, p. 174). In contrast to this, Nīshābūrī, Tūsī, Kāshānī and Theophilus take a complementary point of view. They do not explicitly state that by mixing black and white, the other colors cannot be produced. Instead, all four authors explicitly write that by mixing black and white, a grey color is produced, thus predating the same statement made by Scaliger in 1557 (Shapiro, 1994, p. 608).

Newton possibly learned about the discovery of the painters' three primary colors from his personal copy of de Boodts *Gemmarum* from 1636 (Shapiro, 1994, pp. 614 and 607n16). It is well known that the *Gemmarum* was based in part on the *Speculum lapidum* (1502), a lapidary from Camillo Leonardi, which in turn leaned partially on information from various Islamic authors of lapidaries (Parkhurst, 1971, 1973, p. 424; Mottana, 2006). Therefore a possible transmission of ideas in color science through these lapidaries deserves further investigation.

7. A True Hue Scale

In their lapidaries, Nīshābūrī, Tūsī and Kāshānī chose to ignore the rainbow altogether in their description of color mixing. This also enabled Tūsī to ignore the Aristotelian doctrine and agree with Ibn Sīnā when as we saw before he wrote in response to al-Kātibī that when yellow and blue colors are seen together, a green color is produced (Wiedemann, 1908). This implied a violation of the Aristotelian dogma that all colors are produced by mixing black and white and opposed the Aristotelian observation, quoted above, that green is one of the colors that cannot be produced by painters.

These lapidaries were not the first to oppose Aristotle in this respect. It had been argued before, that for example mixing blue and yellow produces green. This point of view had previously been brought forward by at least three scholars: Alexander of Aphrodisias (d. ca. 200 CE), Abū Bakr al-Kasdānī alias Ibn Wahshiyya in the 9th century and Ibn Sīnā in the 11th century (Fahd, 1974, p. 83; van Campen, 1988, p. 94; Gage, 1993, p. 31).

Although this point of view is obvious for modern readers, it was far from evident to for example Ibn Rushd. In his *Jawāmi' al-āthār al-'ulwiyya* (Short Commentary on the Meteorology: 74, 19–76, 18) he did not agree with Ibn Sīnā's criticism of Aristotle. According to Ibn Rushd, green is not found by mixing the contraries in the sense of more and less, but by mixing them in the sense of obtaining the intermediate quality (van Campen, 1988, p. 95; Lettinck, 1999, p. 292). According to Ibn Rushd, the followers of Aristotle (and perhaps Aristotle himself) had referred to color mixing in a qualitative sense, but not in a quantitative sense (van Campen, 1988, p. 95). Ibn Rushd argues that green is formed by mixing the yellow that exists in light red with the black that is in purple. From a modern point of view, this makes the approach philosophical rather than scientific.

In his lapidary, Nīshābūrī clearly went further than Ibn Sīnā when it comes to producing green by mixing blue and yellow:

> And in every color, there are two extremes: the lightest point and the darkest point.
>
> If yellow, for instance, is mixed with blue, it will result in green [and the green color is an attribute which stands between those two extremes] and excess and wastage are in its both sides;

> and all other colors have the same situation [and between these two extremes, there are various green tones which differ from each other in greenness.]
>
> Among all the colors, it is the green color that contains big differences in greenness among the variants, such as cyan, turquoise, verdigris, viridian and so on. If one of these variations is mixed with another color which is not green, a new color is produced; and since this variation is accurate, the color diversity is unrestricted; and the cause is clear.

This part of Nīshābūrī's text is not fully comprehensible. Apparently, Tūsī was of the same opinion, because he changed the text as follows:

> In every color, there are two extremes: the lightest point and the darkest point.
>
> If yellow, for instance, is mixed with blue, it will result in green. Therefore, green possesses two extremes, like other colors; and between these two extremes, there are various green tones which differ from each other in greenness, such as cyan, turquoise, verdigris (and viridian) and so on. Since this variation is accurate, the color diversity is unrestricted.

This indeed clarifies the text considerably. Kāshānī modified the text further by restoring parts of Nīshābūrī's original text:

> [A]nd in every color, there are two extremes: the lightest point and the darkest point.
>
> If yellow, for instance, is mixed with blue, it will result in green, which is located between two extremes. And there are various green tones which differ from each other in greenness, such as cyan, turquoise, verdigris (and viridian) and so on. If one of these variations is mixed with another color, a new color is produced; and since this variation is accurate, the color diversity is unrestricted.

From these texts it is clear that Nīshābūrī, Tūsī and Kāshānī realized that there are different hues of green, tending towards blue or towards yellow, depending on the relative proportions of blue and yellow in the mixture of these colors (Figure 4).

In modern terminology, this text is the first known description of a hue scale, in contrast to tonal scales which already had been described before. In modern color theory, a tonal scale is defined as a series of mixtures between a color pigment and either black pigment or white pigment in different proportions. In case of mixtures between the color pigment and white pigment, this is referred to as tint scales. If the color pigment is mixed

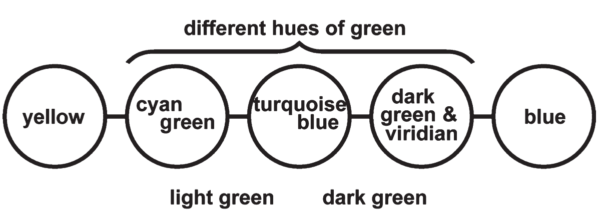

Fig. 4. Color ordering in the range from yellow to blue, according to Nīshābūrī, Tūsī and Kāshānī (reconstruction).

with black pigment, shade scales are produced. Both tint scales and shade scales had been described by Theophilus (ca. 1120).

These scales are contrasted with hue scales. This is the modern term for mixtures between different color pigments (both not being black or white) in different proportions. To date, no earlier description has been found of hue scales other than the texts from Nīshābūrī, Tūsī and Kāshānī discussed here.

In their descriptions of color mixing, Alexander of Aphrodisias, al-Kasdānī and Ibn Sīnā stopped after observing that mixing blue and yellow produces green. But Nīshābūrī, Tūsī and Kāshānī proceeded further by noticing that different mixtures of blue and yellow produce different hues of green. In their hands, the theory of color mixing and color hues obviously became more mature. And although the concept of producing different hues by binary mixing of primary colors had been mentioned before, it had not been described in as much detail as in these Islamic lapidaries.

In the case of Tūsī, this shows that Tūsī was aware of other types of color differences than the different shades of green, moving towards black and the different tints towards white, which he distinguished in his answer to al-Kātibī. The great verbal description of colors differing in lightness, as presented in that text, is now seen to complement the description of colors differing in hue in the lapidaries of Nīshābūrī, Tūsī and Kāshānī.

This does not imply that Tūsī (or Nīshābūrī or Kāshānī) already clearly distinguished between what in modern terms would be called differences in lightness and differences in hue. The cited text fragment shows that in some cases different hues are designated by terms that refer to differences in lightness. Also, most of the color names introduced by Nīshābūrī (and copied by Tūsī and Kāshānī) for the different green hues between blue and yellow are the same as the names used by Tūsī in his letter to al-Kātibī when describing lighter tints and darker shades of green: pistachio (*fustuqī*); verdigris (*zangārī*); naphtha (*naftī*). Apart from these terms, the Nīshābūrī text has one other color term, turquoise/emerald (*zumurrudī*), whereas Tūsī's letter to al-Kātibī mentions two other color terms: leek green (*karātī*) and egg plant green (*bādinjānī*).

We conclude by pointing out that the confusion between lightness and hue we found in Aristotle's color scale (cf. Figure 1) was still present in the work of Nīshābūrī, Tūsī and Kāshānī where it became very explicit. We note that the same confusion is also clear in the work *De Diversis Artibus* of Theophilus (ca. 1120). For example, in Chapter VII of that work Theophilus writes that when green earth and burnt ochre are added to a certain pigment mixture that produces a flesh color, a darker shade of that same color is obtained (Hawthorne and Smith, 1963, p. 18; Dodwell, 1986, p. 7).

8. Implication for Color Ordering

In spite of the confusion between lightness and hue, the five different series of color shades described by Tūsī in his answer to al-Kātibī and reconstructed in Figure 3 already imply a two-dimensional color ordering. Black and white are connected to each other by different branches of color shades. But the different color tones that were described by Nīshābūrī and copied in Tūsī's *Tansūkh-nāme* complete the color network, because they represent a cross-link between the yellow and the blue branches of color shades described in the text to al-Kātibī. Therefore, together these two texts provide strong additional evidence of a two-dimensional character of color space.

Most accounts dealing with the history of color science refer to the work of Parkhurst and Feller.[9] They claimed that it was Grosseteste, who around 1230–1235 in *De Colore* was the first to set aside black and white from the chromatic hues, thereby assuming a two-dimensional rather than one-dimensional color space (Parkhurst and Feller, 1982, p. 225; Parkhurst, 1987, p. 168. Cf. Baur, 1912). However, the textual evidence of Grosseteste doing this is not very clear. In fact, the evidence from Ibn Sīnā doing the same in *Kitāb al-Shifā'* is more clear (cf. Figure 2) and predates Grosseteste's description by more than two centuries. Although there is no clear evidence for the transmission of these ideas, Grosseteste's description of color order may have been influenced by the works of Islamic scholars. He held a position in Hereford, where Arabic science permeated the atmosphere following the return of Daniel of Morley from several years of studying Arabic science in Toledo. One of the topics Daniel explicitly mentioned in this respect was the explanation of color by Islamic scholars (Silverstein, 1948, p. 185; Lemay, 1962, p. 328). Grosseteste himself is known to have been familiar with Islamic work from early in his career (Laird, 1990, p. 684).

9. Conclusions

In their lapidaries, Nīshābūrī, Tūsī and Kāshānī gave a brief overview of color theory. The major part of these texts originates from Nīshābūrī and deviates from the Aristotelian point of view in several ways.

The unique positions of black and white in a color ordering system, as proposed by Aristotle and still valid according to modern color theory, was also adopted by these three authors. Ever since Aristotle, a seemingly logical (but by later standards erroneous) conclusion had been almost universally accepted: black and white were supposed to produce all other colors by binary mixing. But in their lapidaries, Nīshābūrī, Tūsī and Kāshānī do not consistently support this conclusion. Instead, the colors produced when white and black are mixed are described first as 'different colors' and later as grey. Similar to the *De Diversis Artibus* from Theophilus (ca. 1120) in Europe, these texts represent a transition between the Aristotelian point of view that mixing black and white produces all other colors and the modern point of view that only grey is thus produced. The latter insight is believed to be first reported by Scaliger in 1557.

Nīshābūrī, Tūsī and Kāshānī discuss mixtures of blue and yellow in some detail. Like several earlier scholars and in opposition to Aristotle they remark that mixing blue and yellow produces green. But in these lapidaries, a detailed description is given for the first time of a hue scale from yellow to blue that is produced by mixing blue and yellow in different proportions. This text is the first known description of a hue scale. Only tonal scales, obtained by mixing a color pigment with black or white, had been described before.

In the case of Tūsī, this description is complemented by another passage related to colors, which is part of a text written for al-Kātibī. In that text, Tūsī named the various color shades that result when going from white to black, i.e. in the lightness direction of color space. That text had been an elaboration of the similar description by Ibn Sīnā, in *Kitāb al-Shifā'*. But in the *Tansūkh-nāme,* following Nīshābūrī, Tūsī distinguished and named the color tones when going in the hue direction of color space. Together, both descriptions provide a two-dimensional picture of a color ordering system.

The texts in the lapidaries do not consistently distinguish between lightness differences and hue differences. In some cases, differences in hue are characterized by adjectives referring to differences in lightness. The confusion between lightness and hue that is found in the works of Aristotle and Theophilus (ca. 1120) is also found with Nīshābūrī, Tūsī and Kāshānī.

It is possible that the color theories and color orderings described by Ibn Sīnā, Nīshābūrī, Tūsī and Kāshānī influenced European scholars writing on this topic, such as Grosseteste, Leon Battista Alberti, Leonardo da Vinci, Camillo Leonardi and de Boodt (Parkhurst, 1987, pp. 202–203). In the case of the latter two, the color theories are presented in lapidaries, i.e. in the same context as the relevant texts of Nīshābūrī, Tūsī and Kāshānī.

NOTES

1. Mac Lean, 1965; Gätje, 1967a; van Campen, 1988; Morabia, 1991.
2. Aristotle, *Meteorologica* III.2, 372a6-10; Sayili, 1939, p. 69; Lee, 1962, p. 243; Ball, 2001, p. 19.
3. This was stated by Theophrastus in *De Sensu,* 73-5 (Stratton, 1964, p. 137). Also stated by Empedocles, as commented upon by Aetius, *Placita* I, 15, 3 (Diels, 1965, p. 313) and by J. Stobaeus (Meineke and Heeren, 1860, p. 362).
4. Bakos, 1956, Vol. 1: pp. 105–113 and Vol. 2: pp. 75–81; van Riet, 1972, pp. 204–212; Morabia, 1991, p. 703; Kuehni and Schwarz, 2008, p. 34.
5. Theophilus, *De Diversis Artibus*, Book I, Chapter 16 (Hawthorne and Smith, 1963, pp. 23–25; Dodwell, 1986, pp. 14–16).
6. An edition of the text was recently published (Nourānī, 2005, pp. 168–172). Two manuscript copies are well known: (i) Attachment to Berlin 5671 (Ahlwardt, 1893, p. 157), (ii) British Museum 980; 17 (Cureton and Rieu, 1871, p. 453). Apart from these copies, there are other manuscript copies as well: (iii) Tehran University, Meshkāt collection Nr. 389, fol. 44r. (iv) Malek library (Tehran) MS 4694/28. (v) Library of the Holy Shrine, Mashhad (Iran), MS 5590. For this article, we have consulted the London manuscript (as photocopy), and the original Meshkāt and Malek manuscripts.
7. Our translation for this word differs from previous translations, that all go back to Wiedemann's translation (Wiedemann, 1908, pp. 86–91). Only with the different manuscript copies recently having become known, did it become clear that this word appears in different variations. Nourānī

reads *lāzwardī*, i.e. lazur blue (Nourānī, 2005, p. 171). For the Berlin manuscript, Wiedemann also read *lāzwardī*. The Malek manuscript reads *lādjvardī*, an Arabic variant of *lāzwardī*. However, the London manuscript has *zawardī*, as was also read by Wiedemann. Further, the Meshkāt manuscript reads *wardī* (rosy, rose-colored). Interestingly, the Meshkāt manuscript shows that the scribe first wrote *lāzwardī*, but then he crossed out *lāz-*. Apparently, the *–la* ending of the preceding word (*avvalan*—First) easily confused the reading of this color word. Its reading as *wardī* (rosy, rose-colored) is indeed the most probable, since the word *lāzwardī* (lazur blue) already appears in the third color path, and also because it does not fit in the series of reddish colours of the first colour path.

8. Ruska, 1913; Ritter, 1935; Ullmann, 1972; Afshār, 2000; Porter, 2008, p. 610.
9. A notable exception is found in Kuehni and Schwarz, 2008, p. 34.

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