Lovibond 1915

Wilson 1905

Lacouture 1890

Babbitt 1878

Runge 1810

Grassmann 1853

Field 1877

Rood 1879

Itten 1944

Forsius 1611

Gregoire 1820

Newton 1704

Bourges 1918

Birren 1934

Hering 1878

Munsell 1905
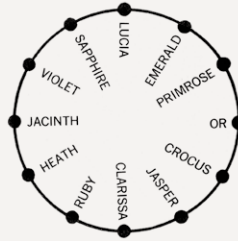

NCS-SYSTEM 1979

Bezold 1874

Irozu-Mondou 1876

Kupka 1910

Runge 1810

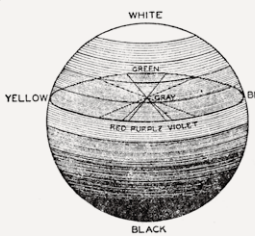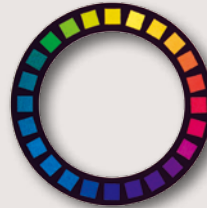Jacobs 1923

Raskin 1825

Bacon 1866
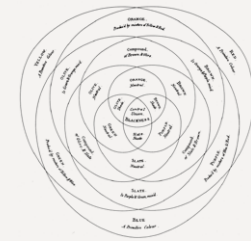
Hayter 1830

Chevreul 1861

Wundt 1874

Ostwald 1917

Hübl 1904

Author unknown 1708

Goethe 1810

Ziegler 1850

Bezold 1876

Herschel 1817

Itten 1944

01 Color Circles
Kunihiko Sugiyama

Who invented color circles?

Color circles are diagrams that graphically express
the concept of color.

Various styles have been used since ancient times,
but circular and spherical diagrams are the most common.
The first step is to consider the simple question:
"Why is color expressed using geometric conceptual schemes
such as circular diagrams?"

When arranged side by side, we see 3,000 years of
color culture history.

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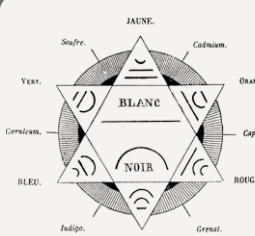
introduction

Looking at the large number of color system charts published in books on chromatics makes one wonder why so many are circular, and which individual might have devised the first color circles.

This topic is touched on in the 2004 Japanese language edition of this publication.

This time, we will use the results of that analysis to study the key color circles in chronological order.

Aristotle
B.C.384–322,
Greece

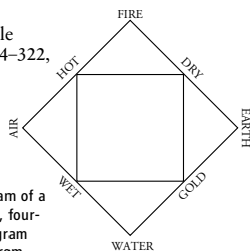FIRE

HOT

DRY

AIR

EARTH

WET

GOLD

WATER

Fig. 1: Diagram of a four-element, four-property diagram that spread from Greece to Arabia. The elementary colors are red, blue, yellow, and green.
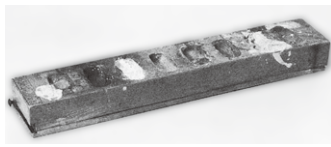
Fig. 2: Eight-color ink well, from Color & Human Response by Faber Birren published in 1978.

The origins of the sense of color
The beginnings with eight colors

How did people in ancient times conceive "color"? This is a question that has fascinated me for a long time. The article "The people that deciphered the rainbow" in the previous issue of this handbook was related to this fascination of mine. A look at the book entitled *ClassiColor: Farven I Antik Skulptur* allows one to see how ancient artists and craftsmen used the color palette.

According to American color researcher Faber Birren (1900-1988), the palettes used by artists in the 4,000 years from ancient times up until the Renaissance consisted of only eight primary colors. Of course, far more colors are seen in the natural world, and this does not mean that ancient people were not able to see a wide range of colors. But it is believed that there was no need to distinguish between the wide range of colors as today, and only a few colors had significant meaning. We see similar observations in the work of French color researcher Michel Pastoureau.

British naturalist and geographer Alfred Russel Wallace (1823-1913) conceived the theory of evolution before Charles Darwin, and wrote his ideas in a letter to Darwin. This prompted Darwin to rush his theory of evolution into publication to avoid being scooped, resulting in Wallace sometimes being referred to as the "man eclipsed by Darwin." One of his works, *Tropical Nature, and Other Essays* (1878), includes some interesting observations on the origins of the sense of color as a naturalist and biologist. While the passage is quite long, it is worth quoting here.

"…It is quite possible that at first, green and blue were the only kinds of light-vibrations which could be perceived at all. When the need for differentiation of colour arose, rays of greater and of smaller wave-lengths would necessarily be made use of to excite the new sensations required; and we can thus understand why green and blue form the central portion of the visible spectrum, and are the colours which are most agreeable to us in large surfaces; while at its two extremities we find yellow, red and violet-colours we best appreciate in smaller masses, and when contrasted with the other two, or with natural tints. We have here probably the foundations of a natural theory of harmonious colouring, derived from the order in which our colour-sensations have arisen and the nature of the emotions with which the several tints have been always associated."

And also quoting from *Zur Entwickelungs-geschichte der Menschheit* (1871) by Lazarus Geiger regarding the development of a sense of color in ancient times:

"The colour of grass and foliage is never alluded to as a beauty in the Vedas or the Zendavesta, though these productions are continually extolled for other properties. Blue is described by terms denoting sometimes green, sometimes black, showing that it was hardly recognized as a distinct colour. The colour of the sky is never mentioned in the Bible, the Vedas, the Homeric poems, or even in the Koran. The first distinct allusion to it known to Geiger is in an Arabic work of the ninth century.⋯Aristotle names three colours in the rainbow—red, yellow and green. Two centuries earlier Xenophanes had described the rainbow as purple, reddish, and yellow. The Pythagoreans admitted four primary colours—white, black, red, and yellow; the Chinese the same, with the addition of green."

These suggest that a wide range of colors was in used in ancient times, but barely described in writing. While there may have been fewer names for the modern-day primary colors, historical works such as *On Colors* by Aristotle and *The Treatise on Color* by Goethe indicate that many color names were in use for flora and fauna.

Research into color starting with Aristotle

The first recorded in-depth studies into color in human history were made by Aristotle and his students (such as Theophrastus). Aristotle's theories on color and the visual sense continued to influence studies of color into the 19th century. It is worthwhile to examine them in detail before discussing color circles.

Aristotle's studies of light and color are discussed in his works *De Anima* (On the Soul), *Sense and Sensibilia*, *On Colors*, and *Meteorology*. According to Aristotle, color is something visible in light, and color is not normally visible if light is not present. Light propagates through the medium of air, an idea related to the Aristotlean theory of visual senses. The explanation of where color comes from is a speculative explanation, and is esoteric enough to make even scholars give up in despair.

To summarize, color is explained as existing on the boundaries (surfaces) of objects. The question of how many colors exist is discussed in *On Colors*, in which Aristotle says that colors range between black and white, and that there are seven different colors (white, yellow, purple, green, blue, gray, and black), just as there are seven different types of flavor, with other colors being mixtures of these seven. This concept was known as the mixture of light and darkness theory. Elsewhere Aristotle writes that gray is an intermediate color between black and white, and while arranging the white-gray-black axis vertically would form a color solid, the explanation was not developed quite that far.

Aristotle's color theories are written mainly in *On the Soul*. Let us now move on to see how Aristotle's color theories sub-sequently developed in the world.

The theory of visual perception originating in Ancient Greece is an essential part of the explanation of color. Plato used the concept of "line of sight" to explain how we see shapes and colors. Aristotle, however, postulated a reverse theory in which objects and colors are seen because the form of a color image (color species) like a cicada's abandoned husk enters the eye from the object reduced to a visual perception pyramid shape with the eye at its apex. Common concepts in ancient color theories included ones in which light was a transparent color, and that what we see are shapes with color. But these explanations included numerous contradictions.

Aristotle's color theories were refined and reassessed by the 11th century Arabian scientist Alhazen, forming the basis of research on the structure of the eye and visual perception theories resembling those used to this day. These are covered the *Book of Optics*. Little remains from the Middle Ages, but in the 14th century, Aristotle's visual perception theories were expanded in *Opus Majus* by Roger Bacon, and perspectivists such as Nicole Oresme.

Optics is the study of light, and the foundations of color research that subsequently took off from the 16th to 18th centuries with the completion of principles of realistic painting were derived from studies dating from the 11th to 14th centuries.
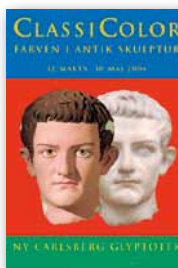

Fig. 4: *ClassiColor Farven I Antic Skulptur*. Indicates that ancient buildings and sculptures were colored. This catalog contains significant evidence to support this.

Mixture of light and darkness theory

Aristotle's explanations of color included the explanation that the myriad of colors consisted of a mixture of light and darkness. In his work *Meteorology*, Aristotle explains that "lines of sight became weaker when reflected, with dark objects becoming darker, and, white objects becoming blacker. He also described how the color (white) of lines of sight became redder when stronger, greener when slightly weaker, and bluer when increasingly weaker." While color is widely discussed in many of Aristotle's works, these are not scientific theories, and minor disparities are noticeable even within his works. The quote above highlighted in blue can therefore be described as a common concept with the mixture of light and darkness theory. So how then does the mixture of light and darkness theory differ from the transformation theory which states that white light is pure light and all colors such as red, blue, and yellow transform according to the degree of darkness intermixed? The transformation theory applies not just to color, so problems arise when we try to collate it directly with the mixture of light and darkness theory. The definition can probably be virtually matched by limiting it to "color transformation theory."
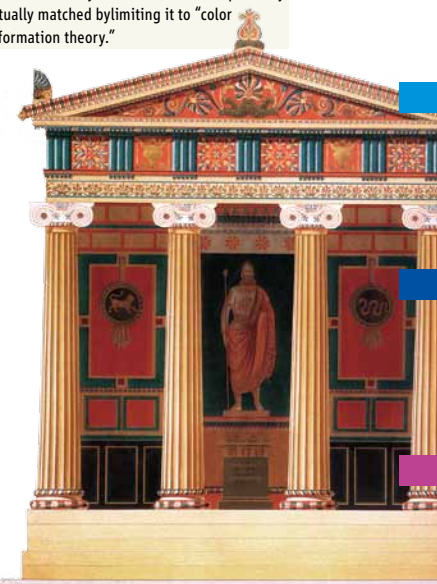

White Yellow Red Purple Green Blue Black

Fig. 3: Aristotle's seven basic colors. Gray is subsumed under black.

Who invented the color circle?

The idea of arranging colors in a circle

Aguilonius
1567–1617,
Belgium

Robert Fludd
1574–1637,
United Kingdom

Francis Glisson
1597?–1677,
United Kingdom

Athanasius Kircher
1601–1680,
Germany

Fig. 5: The upper wind rose was taken from Aristotle's *Meteorology* printed in 1519. The lower wind rose is from Cardano's *Opera Omnia* (1663). The origins of color circles lie in wheels such as wind roses.

Note 1: Monochord means "single" in Greek, and more specifically refers to a string instrument with a single string in accordance with canonic stipulations. The ratio of the string can be varied by moving the bridge along the string.

The first color circle

Here we will consider which individual first invented what we today refer to as color circles and hue circles.

It is difficult to ascertain whether early color circles applied to artists' paint colors or to light, and this ambiguity persisted even after Newton had explained the characteristics of light. Here we will look at and compare a wide range of color concept diagrams and items used in design teaching, including circular and spherical systems, not limited to what are referred to as color systems in chromatics.

From ancient times up until the Middle Ages, circular diagrams were produced in great quantities, including those for horoscopes and wind rose diagrams (Fig. 5), and for annular diagrams for calendars. So it is likely that colored versions of these tools formed the basis for the idea of color circles. Early color circles can also be seen in works related to alchemy, which had continued to attract attention since ancient times. Also, early medicine was based on diagnosing the color of bile and urine, which required foundations for the order in which to arrange colors, such as urine color circles.

It was not until the 18th century that color circles became widespread. Color circles in this period began to develop from the ancient concept diagrams into practical tools for use in color assortment and color matching in areas such as the textile industry.

Monochord diagram

The Ancient Greek mathematician Pythagoras devised the harmonics of sound. The harmonic relationship of the seven tones of the do, re, mi, fa, sol, la, ti chromatic scale was expressed until the Middle Ages using a variety of different diagrams. This was referred to as the monochord theory in the Middle Ages, and the color diagrams conceived by Aguilonius, Glisson, and Kircher, were clearly monochord (Note 1) style diagrams from classical music adapted for use with color. These diagrams had black and white arranged at the ends, with other colors arranged in between, clearly derived from Aristotle's color theory. Looking at these diagrams, it does not appear that Aristotle's color theory targeted a color circle or color solid.

Color circles in medicine

Robert Fludd was a British physician, a member of the secretive Rosicrucian society, and a proponent of Hermes Trismegistus. His work *Medicina Cathorca* (Frankfurt, 1629) includes a color ring diagram (Fig. 7). The 2nd century thinker and proponent of gnostic Basilidas of Alexandria is said to have compared the seeds of the world to peacock eggs laid inside the seven colors of the regions of the earth. The seven colors on Fludd's color ring were red, orange, yellow, white, black, blue, and green (Fig. 7), clearly reflecting gnosis, based on the four main elements of Aristotle. Black and white represented both extremes of darkness and light, while red lay between. Orange and yellow were arranged between red and white, and green and blue were arranged between red and black. Fludd also worked on measuring the color of urine and invented a urine measuring device. He believed that color was not simply symbolic, but an important diagnostic tool in medicine.

The oldest color circle printed in color

The color circle by an unknown author and printed in the Netherlands is an illustration related to pastel tones. It was printed after Newton's *Opticks* was published in 1704, and the 7-segment diagram shown on the left-hand side in Fig. 10 appears to have been influenced by this.

Color Circles Shown in Diagrams- 1

Fig. 6: Aguilonius considered the relationship with Pythagorean rhythm while adhering to Aristotle's theories. Phase transforming this diagram suggests the color solid shown to the right.
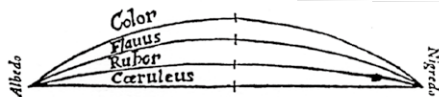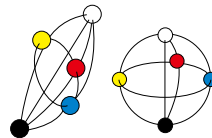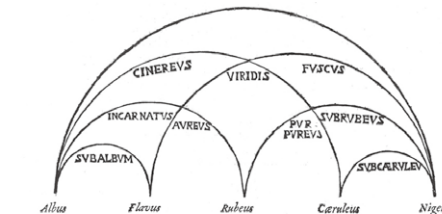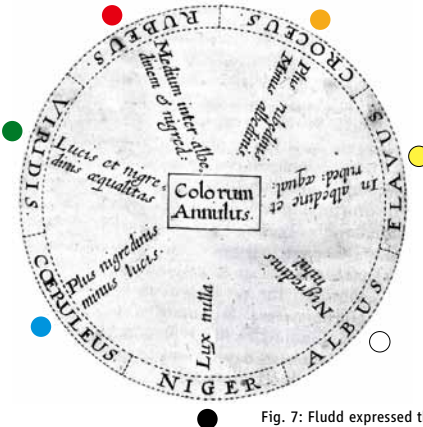

Fig. 7: Fludd expressed the color perception of alchemy in his circular "Color wheel" diagram (1629).
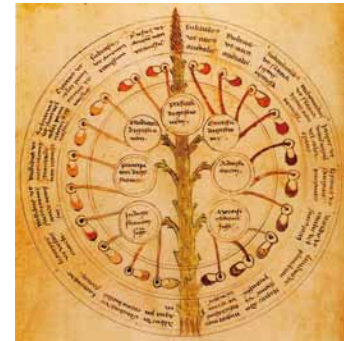

Fig. 8: Color of urine: John of Cuba, Hortus Sanitatis 15th century urine color charts used by physicians in the Middle Ages to diagnose the color of urine expressed the sequence of colors from yellow to red as variations from white to black.

Fig. 9: Color scale devised by Glisson (1597? – 1677, Britain), a physicist at Cambridge and royal advisor. Blue, red, and yellow were located between black and white at the ends, with the horizontal line forming a grayscale (1650).

Fig. 11: Color circles published by the printer Vandore in The Hague, in the Netherlands in 1708 (author unknown) with seven and twelve colors. These color circles are said to be the oldest color circles printed in color. From the initials C.B, it is conjectured that the author may have been Clause Boutet.
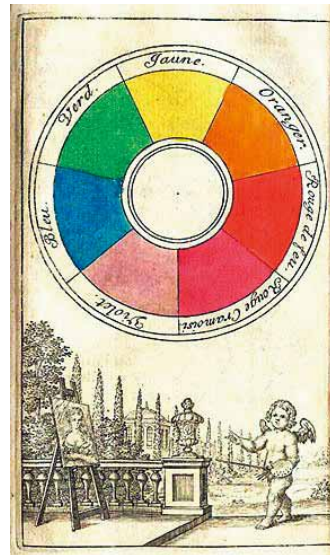
Fig. 10: Graphic representation of Aristotle's theories produced by the learned visionary scientist Kircher. He explained the Aristotlean variety of colors in chapter 2 of Ars Magna Lucis et Umbrae by modifying Aguilonius's diagram.

Color Solid Idea

How did Color Circles become color spheres?

Robert Grosseteste
c.1168–1253,
England

Leon Battista Alberti
1404–1472,
Italy

Leonardo da Vinci
1452–1519,
Italy

Aron Sigfrid Forsius
?–1637,
Sweden

Robert Grosseteste's understanding of light and color

Robert Grosseteste was the first chancellor of Oxford University and the author of the treatise *On the Rainbow* around 1230, describing his unique understanding of color gained from translations of Aristotle's works. "…There are seven colors close to white, no more and no fewer. These colors are created through transformations further away from white. … Similarly, there are seven colors close to black, and these rise from black to white until they meet with the colors descending from white. White has three properties: the amount of light, the brightness of light, and the pureness of the transparent body. One of the three will attenuate if two remain unchanged, creating three different

Fig. 12: A diagram illustrating the sketches drawn by Leonardo da Vinci.

colors. … This is how seven colors in total are created from white." (*On the Rainbow*, collection of Christian mystic works)

This description clearly brings to mind the arrangement of a color solid. The choice of seven colors (the actual colors are not indicated) is based on Aristotle's provisions, and probably led to the seven colors of the spectrum specified by Newton. I would envisage "the amount of light, the brightness of light, and the pureness of the transparent body" as corresponding to hue, intensity, and saturation, but perhaps this is an excessive leap of imagination.

Leonardo da Vinci's primary colors

The leading Renaissance painter Leonardo da Vinci did not write much about chromatics, but he does mention color briefly in his *A Treatise on Painting*. According to da Vinci, there are six primary colors: white (light, sun), yellow (earth), green (water), blue (air), red (fire), and darkness (black). These six primary colors can be described as predecessors of the six fundamental colors of the NCS (Natural Color System) color order system used in the 20th century.

Alberti's color solid

One of the leading Renaissance architects, Leon Battista Alberti, wrote very briefly on topics related to color in the first part of his work *On Pictures* (1436). "… The true colors

consist of just four primary colors. These give birth to other kinds of colors. Red is the color of fire, light blue is the color of the atmosphere, water is green, and earth is brown (yellow) and gray. Other colors such as jasper and sulfur are mixtures of these colors. These four colors are thus parent colors, and combining them with darkness (black) and light (white) creates their color variations of their own…" This description brings to mind a double-cone color solid, and also a three-dimensional four-element, four-property diagram. (See Fig. 14 and 15)

Mathematician Forsius's color sphere idea was the first diagram

Early in the 20th century, detailed sketches of a color sphere were discovered in a notebook belonging to the Swedish mathematician Aron Sigfrid Forsius. That notebook was written in 1611, which indicates an advanced level of completion for the early concept of the color sphere. (The sketch itself was not colored, however.) Whereas the ideas of Grosseteste and Alberti are purely conjectural, Forsius's idea clearly envisaged an overall arrangement of color perceivable by humans. This can therefore, without doubt, be described as the world's oldest color sphere (color solid).
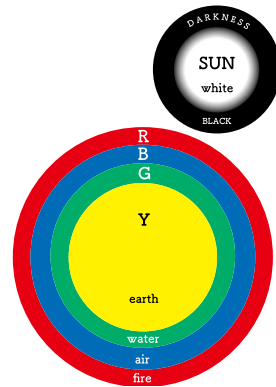
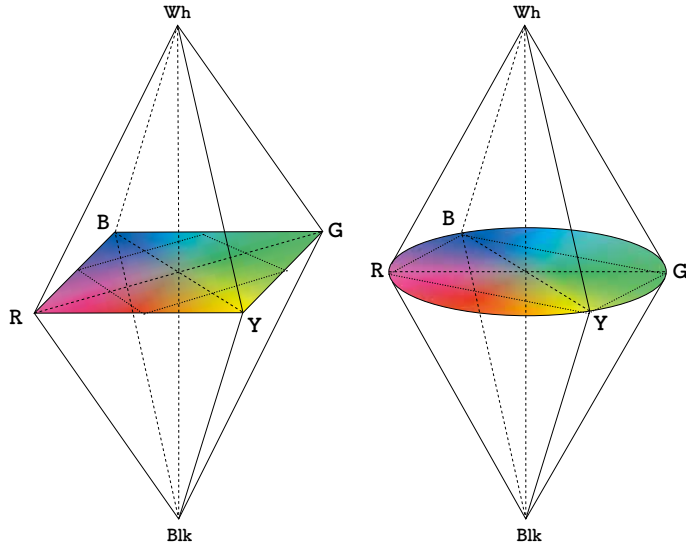# Color Circles Shown in Diagrams- 2

Fig. 14: (Avove) Expressing Leon Battista Alberti's relationship between the four primary colors of red, blue, green, and yellow with black, gray, and white enables it to be three-dimensionally visualized in an arrangement as shown in the two figures above.
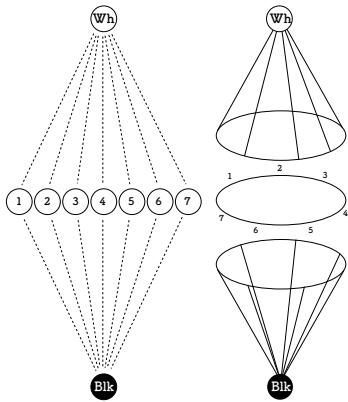

Fig. 13: (Above) Robert Grosseteste's relationship between the seven colors and black and white. (Above) An illustration showing this idea as a double cone.
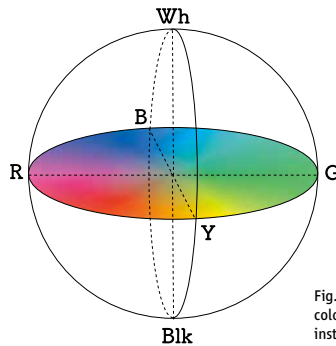

Fig. 15: (Left) It can also be visualized as the color solid shown below if treated as a sphere instead of a double cone.
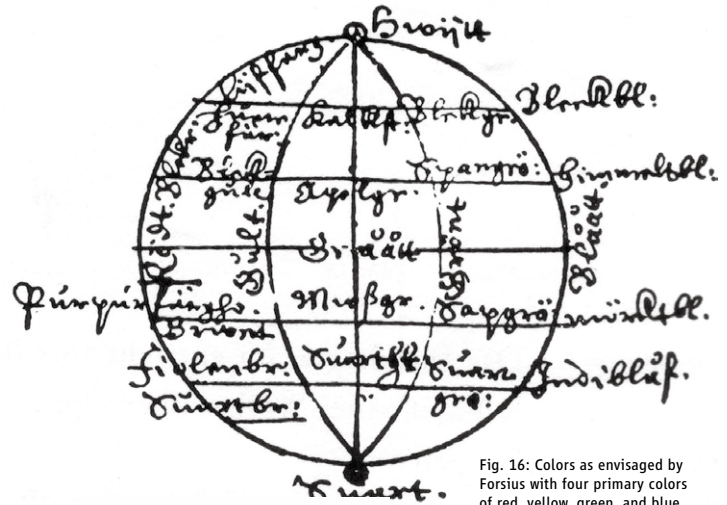
Fig. 16: Colors as envisaged by Forsius with four primary colors of red, yellow, green, and blue arranged on the equator line, and with a grayscale line as the vertical center axis from white (heaven) to black (earth).

White

Life colour — tree and wheat colour — chalk grey — pale blue

Pale red — pale yellow — apple mould — verdigris — sky blue

Red — yellow — grey — green — blue

Purple — flame yellow — mouse grey — grass green — dark blue

Violet — black brown — black grey — black green — indigo

Black

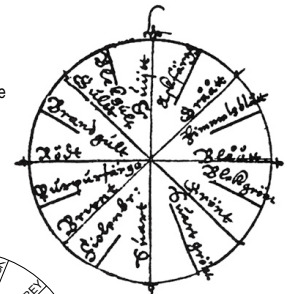**Fig. 17:** English nomenclature for Fig. 16.

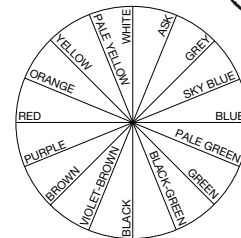**Fig. 18:** Forsius color circle viewed on the equator.

Fig. 19: English nomenclature for Fig. 18.

Birth of the color circle

Differences between light and paint clarified by explanation of light

Newton used the word spectrum, meaning "apparition," in Latin, to describe the color band produced by triangular prisms.

Newton discovered that the seven colors contained in white light rays were diffracted differently to create the rainbow phenomenon.

Isaac Newton
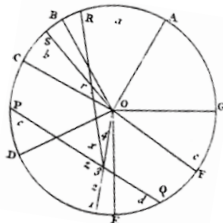1642–1726,
England

Moses Harris
1731–1785,
England

Fig. 20 : If inverted from left to right, this illustration entitled "Shadows and reflection" in *Linear Perspective* (1715) by Brook Taylor (1685 – 1731) virtually coincides with Newton's color circle. The two lines appear to verify Newton's center of gravity laws.

Was Newton's color circle a chromaticity diagram?

Some 50 years after Forsius's color solid idea, Cambridge University professor Isaac Newton conducted experiments exploring sunlight. He included his famous color circle in his work *Opticks*, published in 1704. Newton described his color circle as transforming from the seven colors arranged around the circumference towards white in the center, with the intermediate colors determined by their specific positions. The small circle indicated a centroid of the arc divided into seven.

The seven colors of light (red, orange, yellow, green, blue, indigo, and violet) are arranged around the circumference, but all the colors of the spectrum are actually considered to be arranged around the circumference. (However, since this is a schematic diagram, these colors do not coincide with the actual spectrum wavelength positions.) It may be that Newton did not color his color circle because it represented the colors of light and not pigments.

Perhaps Newton's color circle is frequently discussed due to the various techniques hidden within it. One was the way in which Newton fitted his own color circle to the seven tones of the musical scale. This is firmly believed to be influenced by the illustration included by Descartes in his work *Compendium Musicae*. When overlaid, the center angles for each color match almost perfectly.

Another point is that Newton describes the center of the color circle as white, so one should visualize the seven spectral colors arranged around the circumference transforming toward the center. Moreover, when Newton writes that the color of a specific point within the circle can be determined using the center of gravity rule, it becomes possible to envisage this diagram as a circular chromaticity diagram.

The center of gravity rule is relatively easy to understand and can be considered an excellent way of describing unspecified colors without using the concept of vectors. In his book *The Artful Universe*, physicist John D. Barrow includes a spherical interpretation as shown on the bottom left. No one else has made such a bold interpretation.

Fig. 21: Musical scale diagram included in Descartes' *Compendium Musicae*.

Two color circles by entomologist Moses Harris

Some color circles are noted for their beauty. These include the two color circles that form part of the work *Natural System of Colours* published in 1766 by British entomologist and engraver Moses Harris. This is a precious work in the field of chromatics, with only four copies known to exist. Schiffermüller, discussed in the next section, was also an entomologist.

Harris created two color circles entitled "Prismatic" (prismatic color circle with three primary colors red, yellow, and blue) and "Compound" (compound color circle with three primary colors orange, green, and purple) (see Fig. 24). The prismatic color circle on the bottom left is formed of 18 colors mixed from the three primary colors red, yellow, and blue. Despite using the term prismatic, Harris made the error of using the subtractive color mixtures red, yellow, and blue as the prismatic primary colors.

Harris's forté was engraving, and he uses the density of black lines to represent the 20 intensity gradations for each color toward the center of the circle. The colors were added using watercolor, an impressive achievement in an age before dot color printing. It is no exaggeration to call these color circles, alongside those of Chevreul, the most beautiful known to exist.
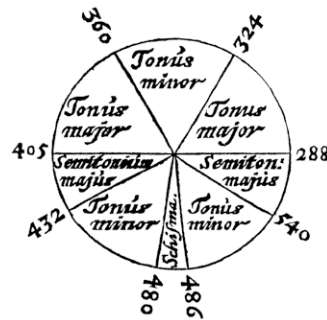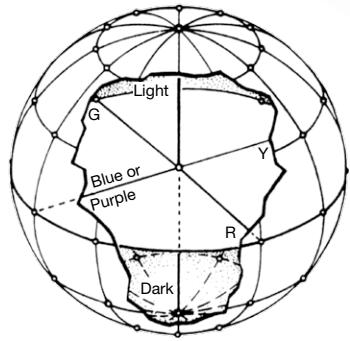
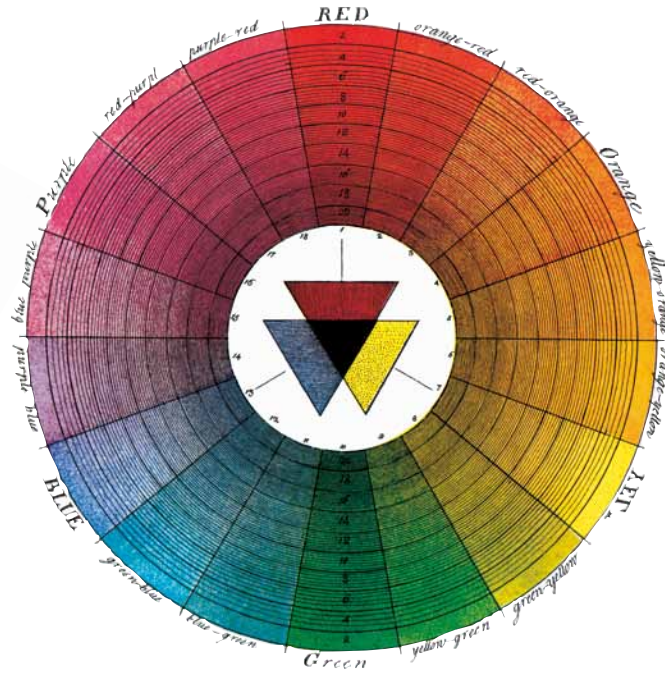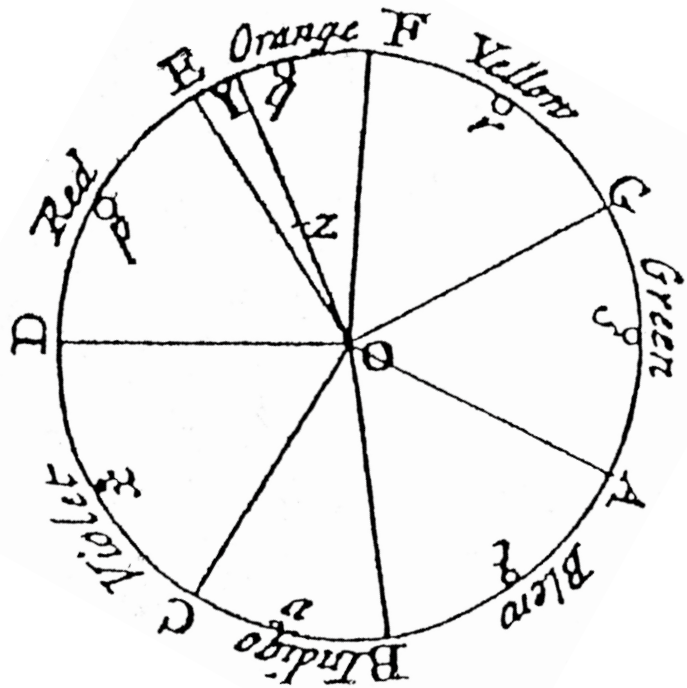# Color Circles Shown in Diagrams- 3

Fig. 22: Newton used this diagram to illustrate how the colors of the spectrum produced white when mixed, but he also considered the correspondence between the seven colors and the seven musical tones.

Fig. 23: Illustration from *The Artful Universe* (1995) by John D. Barrow.

Fig. 24: (Three diagrams on right) Harris was a skilled engraver, increasing the number of engraved black lines to adjust the intensity, with three lines for level 4 and 12 for the innermost level 20. He illustrated a total of 660 colors (360 for the prism color circle and 300 for the compound color circle).
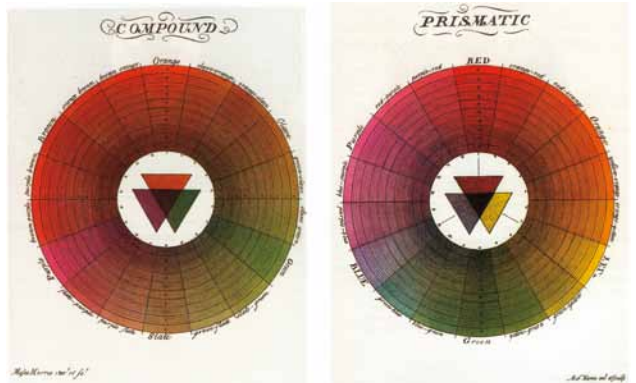
Mystic color circles

From late 18th to 19th century

Fig. 25: Ignaz Schiffermüller
(1727- 1806, Austria)

Johann Wolfgang von Goethe
1749–1832,
Germany

Phillip Otto Runge
1777–1810,
Germany

Color circle devised by an entomologist

Austrian entomologist Ignaz Schiffermüller published a beautiful illustration containing the color circle shown to the left in his 1772 work *Versuch eines Farbensystems*. An unusual feature of this color circle was the use of continuous gradations. The color circle consisted of a total of twelve colors, including the four primary colors of red, blue, green, and yellow, and eight other secondary colors, and the twelve colors were given unique names. The center of the circle contained the sun–the source of all color. The four illustrations with a rainbow theme clearly show a mixture of pigment and light colors.

Goethe's color circle

The literary figure Goethe began studying chromatics in his 40s, devoting two-thirds of his life to the study of chromatics. His three-part work, *Zur Farbenlehre* (Theory of Colors), was published in 1810, by coincidence the year in which Runge died. A proponent of Aristotle's color theory, Goethe believed color existed between black and white. Goethe regarded color perception to be a psychotropic effect and conducted physiological experiments to invent a color circle for the six colors occurring in residual images. He explained this in terms of the two pure colors, yellow (light) and blue (dark) under the concept of Steïgerung (elevation), developing this into a theory of color harmony (Fig. 27). Goethe produced two different color circles: one a six-color circle (Fig. 26) without Newton's somewhat forced addition of indigo. This six-color circle is a color circle made up of three pairs of complementary colors (red-green, purple-yellow, blue-orange) based on residual image colors. Produced with assistance from Friedrich Schiller, the other color circle (Fig. 28) consisted of crimson, orange, yellow, green, blue, and purple arranged around the circumference, with black at the center. The outermost ring is divided into choleric, sanguine, phlegmatic, and melancholic, with these temperaments each further divided into three.

Goethe's color circle epitomizes his color theories, and the theories were positively inherited alongside with those of Itten and Klee of Bauhaus, as well as Runge, and incorporated in design teaching. Readers interested in learning more are encouraged to read Goethe's greatest work, *Theory of Colors*, although tremendous patience is necessary due to its length.

Runge's color sphere

Runge was an artist who built the foundations for the German romantic painting style. He devoted his later years to the study of color. Runge published his color theory and color sphere diagram (Fig. 29) in his work *Farbenkugel* in 1810 before dying in the same year at the early age of 33. Runge's color sphere was clearly modeled on the Earth. A color circle for pure colors lay at the Equator, with black placed at the South Pole and white at the North Pole and the axis connecting the two poles forming a grayscale. All mixed colors are thus present within the sphere.

Issues with the structure of Runge's color sphere were highlighted a century later by Professor Ostwald (Wilhelm Ostwald). He understood that adding white or black to the colors on the equator of the sphere, shifting them toward the two poles, reduced the number of mutually differentiated colors, and that having gradations along the surface of the sphere was an error. He proposed that they should instead vary linearly. Nevertheless, this color sphere was praised by Johannes Itten and Paul Klee of Bauhaus in the 20th century, with Runge's ideas being incorporated into standard teachings on color.

Runge's work *Farbenkugel* has been reprinted and can be downloaded in PDF format on the Internet, but is currently available only in German. I was able to view the original at the Goethe-Museum in Düsseldorf.
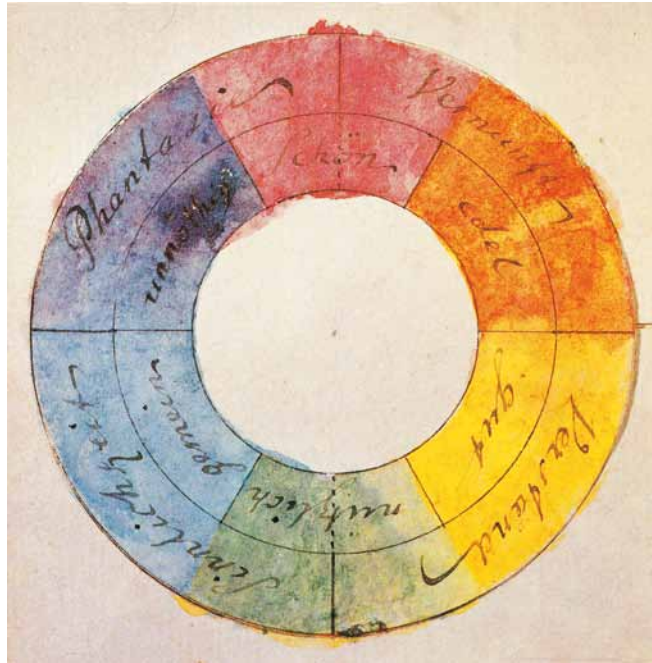
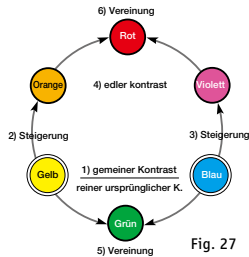# Color Circles Shown in Diagrams- 4

Fig. 26: Symbolic use of color

Fig. 27

Fig. 27: Steïgerung (elevation). Goethe used a color circle to explain his concept of "Steïgerung."

Fig. 28: Color wheel illustrating the human temperaments, created with assistance from Schiller. It consisted of crimson, orange, yellow, green, blue, and purple arranged around the circumference with black at the center. The outermost ring is divided into choleric (autocrat, hero, adventurer), **sanguine** (good person, enthusiast, elegant person), **phlegmatic** (teacher, historian, orator), and **melancholic** (philosopher, scholar, monarch). The traits in parentheses are located in the middle.

Fig. 28
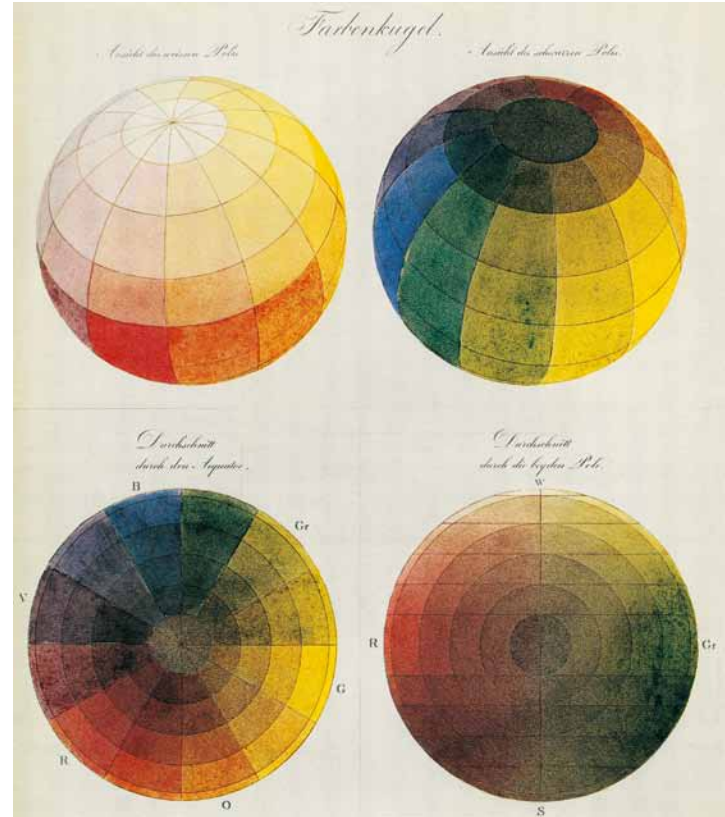
Fig. 29: Runge's color sphere. The diagram is a colored engraving.
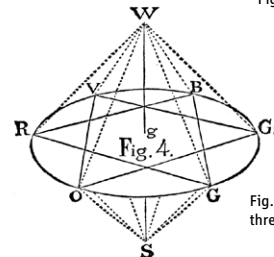
Fig. 30: Diagram contained in Farbenkugel by Runge. It is a three-dimensional version of Goethe's color circle.

Color harmony and color solids

The beginnings of practical color theories

Michel-Eugène Chevreul
1786–1889,
France

Charles Henry
1859–1926,
France

Fig. 31: Chevreul's tone scale (for Blue).
Pure color is located midway.

Fig. 32: From Charles Henry's *La Lumiere, La Couleur, La Forme* (1922).

Chevreul's color system originating from the illusion of color

French scientist and chromatic researcher Michel-Eugène Chevreul devised a color system for color harmony, publishing this in his work *The Principles of Harmony and Contrast of Colours* in 1839. This work won high praise as a book on color theory encompassing all aspects of color, from painting and pigments to printing. His subsequent book *The Principles of Harmony and Contrast of Colours, and Their Applications to the Arts*, published in 1864 (diagrams printed in 1855) became a color theory manual for Impressionist painters at a time of significant changes in the art world. Chevreul's color circle was printed using lithography and received the gold award at the Paris Expo held in 1855.

Not long after being appointed director of dyeing at the Royal Manufactory of Gobelins in France, Chevreul received complaints concerning the poor quality of the colors, including blue, mauve, gray, brown, and black. His investigations into the problems marked the beginning of his serious studies into color. His research showed that the phenomenon did not involve problems with dyeing technology, but was attributable to the different ways in which a thread of a certain color appears when woven next to other colors, rather than viewed alone. This was the phenomenon in which colors appear lighter when surrounded by dark colors and darker when surrounded by light colors, a fundamental aspect taught in the first stages of chromatics today. He also identified the existence of a contrasting effect in the coloration for complementary color relationships. This was likely the first research in the world in which color arrangement was applied to industrial productivity.

Let us now examine Chevreul's color solid, referring to the three-dimensional structure in Fig. 35.

The color solid is a hemisphere with white at the center of the base, pure colors arranged midway, and tones (ton) varying toward the circumference. Fig. 31 shows the 20 tone gradations from white to black.

Chevreul's color solid is based on the three characteristics of hue, tone, and turbidity. Chevreul called the gradations toward the center axis turbidity (ton rabattu). The turbidity of colors declines toward the base toward the center axis and increases in a conical arrangement. The center axis is achromatic color, from white at the lower end, through gray, to black at the top. The common image we have of color solids usually consists of pure colors arranged around the equator with white at the upper pole and black at the lower pole. Chevreul's color solid, however, uses black for the exterior, with the base becoming white and individual hues arranged midway along the hemisphere, making it difficult to visualize. For this reason, it is occasionally misinterpreted, even in academic publications.

Charles Henry's color sphere

Charles Henry was an assistant librarian at the Sorbonne, an assistant professor at the institute of higher education, and a mathematician and philosopher on esthetics who held the important position of director at a psycho-physiological laboratory. He included color reproductions of a color sphere (Fig. 32) in his works Cercle Chromatique (1889) and *La Lumiere, La Couleur, La Forme* (1922). These works examine the relationship between color and musical scales from a mathematical perspective. His works contain equations and graphs, giving them a somewhat daunting aspect, but the color sphere immediately betrays the influence of Chevreul.

Henry was in contact with numerous artists, including Georges Seurat and Paul Signac, and was a supporter of the theories of the new Impressionists.

Color Circles Shown in Diagrams- 5

Color solid diagram

Divided color circle diagram

Turbidity-0

Turbidity-1

Turbidity-2

Turbidity-3

Turbidity-4

Turbidity-5

Turbidity-6

Turbidity-7

Turbidity-8

Turbidity-9

Fig. 33: Ton rabattu from Chevreul's *Exposé d'un moyen de definer et de nommer les couleurs* (1861).

(Fig. 33 and 34 are used with permission from Akira Kitabatake's *Key Works in Chromatics*.)
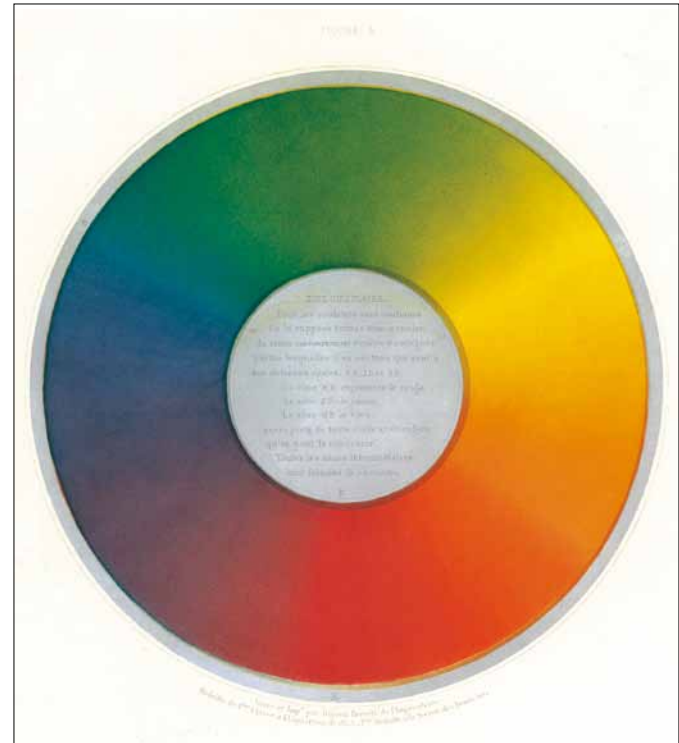
Fig. 34: Chevreul (1861)

Fig. 35: Chevreul's three-dimensional color solid

Constant hue plane
(h = 0, 6, 12, ... 66)

Constant lightness plane
(d = 4, 16, 20)

Constant turbidity plane
(b = 0, 3, 6, 9)

Courtesy of Mitsuo Kobayashi (honorary professor, University of Electro-Communications)

Musical and color harmony

System of light and pigment from the explanation of light

Fig. 36: Color scale

George Field
1777?–1854,
England

Fig. 37: From *Chromatics*: or, An essay on the analogy and harmony of colours (1817).

Mystic Field's color circle

British dye researcher and pigment manufacturer George Field described his unique harmony theories in a number of books based on the results of developing pigments and dyes. Notable works include *Chromatics* (1817), *Chromatography* (1835), and *Rudiments of the Painters* (1850). As well as being a scientist, he was a proponent of Aristotle's color theories. Fig. 36 shows the illustration (not a color circle) included in *Chromatics*. This diagram is also used in the diagram showing the musical scale and color in Fig. 40. The arrangement of colors between black and white at either end reflects the Aristotelian perception of color. The numerous color illustrations included in his works also convey a sense of mysticism.

Field's color circle naturally uses pigment color mixtures, with the three primary colors arranged like overlapping petals with the center containing achromatic black. The tertiary color within the petals is expressed as Dk.

Perhaps the most interesting aspect is the quest for similarities between color and shape with a comparison of the three primary colors, red, yellow, and blue, to the musical scale do, mi, and so, and to the three primary figures of lines, angles, and curves. As with the secondary colors, when the secondary shapes (pyramid, cylinder, cone)

meet at the center of the sphere, the respective base area ratios approach the harmonic ratio (5:3:8) of the three primary colors derived by Field, suggesting a quest for a principle unifying color and shapes. No doubt this was inspired by Kepler's attempts to derive the laws of planetary motion from inscribed platonic solids.

Field's color harmony theory used an experimental device called a metrochrome, which he devised to define the color harmonies of the three primary colors of red, yellow, and blue as a compound ratio. The metrochrome featured three wedges engraved with a scale according thickness, as shown in Fig. 39. If three primary color solutions were added and overlaid to observe the transparent colors through the viewing glass, an achromatic color could be obtained for the ratio red 5 : yellow 3 : blue 8. This ratio defined the harmony color mixture as the area ratio. In other words, the ratio of 5:3:8 formed the harmony datum ratio. This was a ground-breaking idea from the point of expressing color harmony quantitatively, but it was also criticized for this reason by the likes of Bezold, Brucke, and Rood, aside from criticism of the analogy to the musical scale.

The contributions of Field's research into pigments and dyes in the area of industrial technology was highly acclaimed at the time, but appears less widely acknowledged in later color research.

Irozu-Mondou and its debt to Field's color circle

The Meiji Restoration in Japan brought about tremendous changes in education. 1872 saw the publication of The *Elementary Education Guide*, based on practices from the West. The first textbook in Japan on color, *Irozu-Mondou*, is influenced by the theories of Newton, Field, and Chevreul, with Wilson's diagram (Fig. 41) incorporated without modification. This diagram was printed using woodblock printing, with separate wood blocks for each color. Comparing the left and right diagrams on the right-hand page shows that the Japanese diagram is identical to Field's diagram, except for the circle of achromatic color in the center. The actual colors used in the printing clearly differ, but this is due to the materials used in printing.

While color research in Japan began much later than in the West, this volume marks the clear start of color research in Japan.
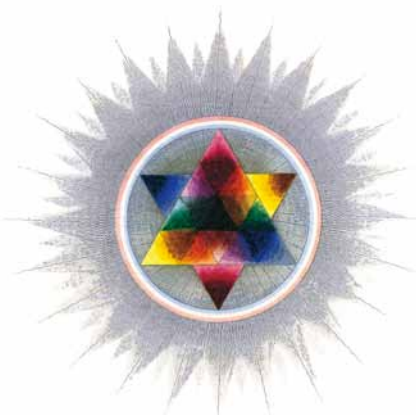
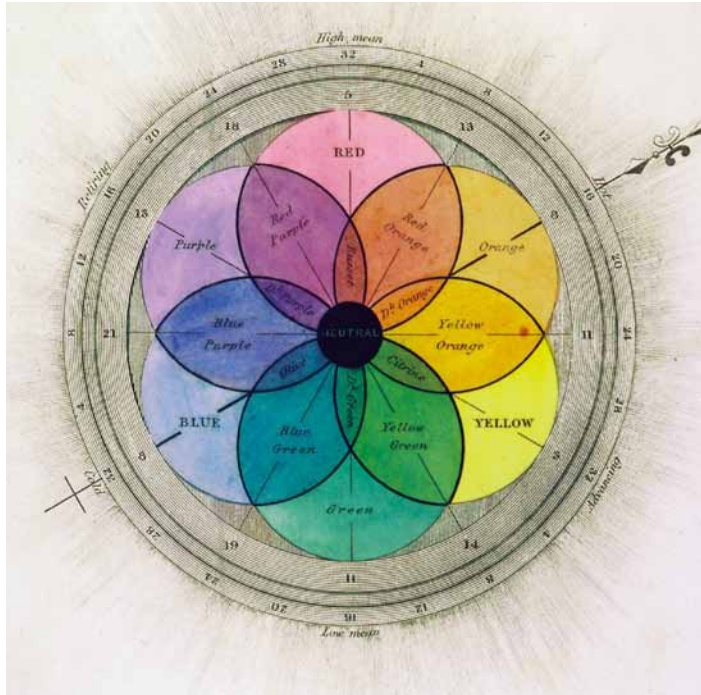# Color Circles Shown in Diagrams- 6
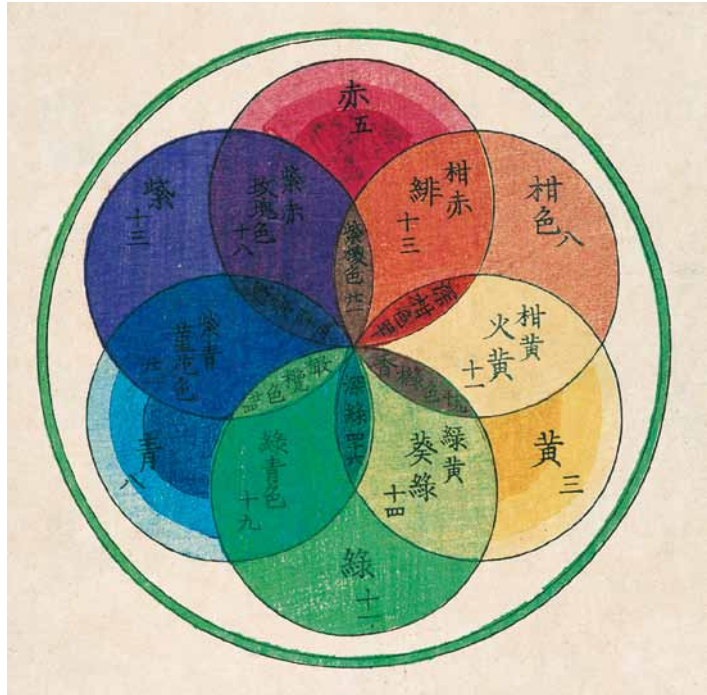

Fig. 38: Field's color circle (1841).

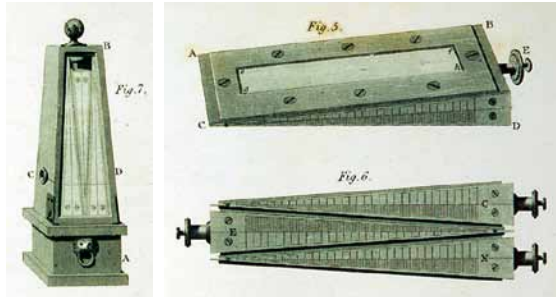Fig. 41: Three primary colors and color mixing diagram in *Irozu-Mondou* (1876).
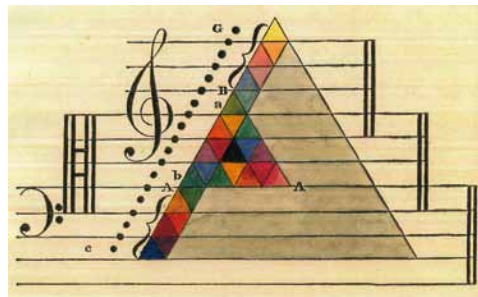

Fig. 39: Experimental color harmony metrochrome.
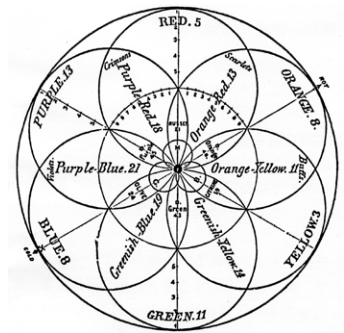

Fig. 40: Field's color and sound comparative scale.

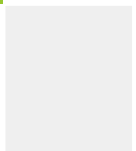Fig. 42: Color diagram by Wilson (USA).

In search of applicable theory

Building the foundations of modern chromatics

Hermann Günther Grassmann
1809–1877,
Germany

Hermann Ludwig Ferdinand von Helmholtz
1821–1894,
Germany

Ogden Rood
1831–1902,
USA

Wilhelm Max Wundt
1832–1920,
Germany

Karl Ewald Konstantin Hering
1834–1918,
Germany

Grassmann's color circle

German mathematician Hermann Günther Grassmann is famous for Grassmann's Law for color, which allows color to be expressed as a color space vector consisting of three-dimensional RGB coordinates. Grassmann's 1853 color circle (Fig. 43) moves the spectrum start and finish point to the 12 o'clock position, based on Newton's color circle, and the boundary lines for Newton's initial red and final violet are assumed to correspond to the Fraunhofer B and H lines. Symbols indicated on the Fraunhofer spectral diagram are included inside the circle verifying the positions of adjacent colors in detail. Grassmann contributed to the foundations of modern chromatics, his color circle analysis draws on a classical approach.

Helmholtz's color circle

Hermann von Helmholtz, a German physiologist and physicist, made significant contributions in physiological optics and acoustic physiology. He developed and presented the theory relating to the three primary colors of light proposed some 50 years earlier by Thomas Young (the Young-Helmholtz's physiological trichromatic theory), which made it possible to explain the colors of residual images and color blindness. The color circle in Fig. 44 shows a cone-shaped color solid as

viewed from above. The line through purple likely means the color was not found in the spectrum.

Wundt's color sphere

Wilhelm Wundt, a German physiologist, philosopher, and psychologist, is often called the father of experiment psychology. Published in 1874, Wundt's color sphere can be seen as a development of the classical Newtonian color circle. However, the center angles differ significantly from those of Newton, although it is unclear whether this is arbitrary or deliberate. The center of the sphere is, as expected, neutral gray.

Hering's four-primary-color color circle

Focusing on color perception, Ewald Hering in 1878 proposed the opponent color theory, which sought to overturn the mainstream Young–Helmholtz theory. It did not win wide acceptance. According to the principles of mixed colors, yellow is created by combining red and green in the three RGB primary colors. However, Hering focused on observation results indicating that red and green hues could not be sensed simultaneously from yellow; red and green hues could not be sensed when observing specific colors; and yellow and green hues could not be sensed simultaneously. These observations prompted him to question the theory of three primary

colors. Hering's theory assumed three fundamentally perceived opponent color pairs of red-green, yellow-blue, and black-white. He also theorized that the retina included black/white, red/green, and yellow/blue receptors, speculating that these receptors underwent contrasting changes of "dissimilation" and "assimilation" due to light. Hering's innovative color circle in Fig. 49 suggests that individual secondary colors can be extracted by mixing in the ratios of the lines a, b, c and a', b', c' in Fig. 48.

The Young-Helmholtz trichromatic theory and Hering's opponent color theory are both considered valid today, based on the stage theory of color vision that the neural information processing involved in color perception depends on the stage of visual sensation.

Ogden Rood's complementary color circle and harmony color circle

Ogden Rood was an American physicist, professor at Columbia University, and an amateur painter. Rood's most important work is *Modern Chromatics*, published in 1879, in which he provides his famous color chart (Fig. 46), clearly illustrating the differences between the colors of pigment and light. His work was published in French in 1881, becoming the color bible of the neo-impressionist painters at the time. Pissaro, Seurat, and Signac ↗
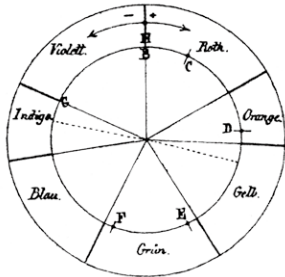
Color Circles Shown in Diagrams- 7

Fig. 43: Grassmann's color circle (1923).

Fig. 45: Rood's pigment complementary color relationship diagram (1879).

(a)

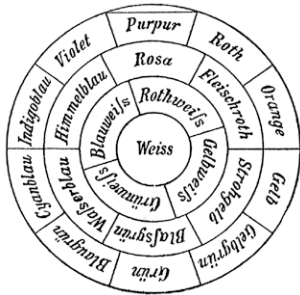Fig. 48: Hering. Diagram to illustrate similar hues as ratios of individual hues.

Fig. 44: Basic plan for Helmholtz's color cone (1867). Saturated primary colors are located on the periphery.

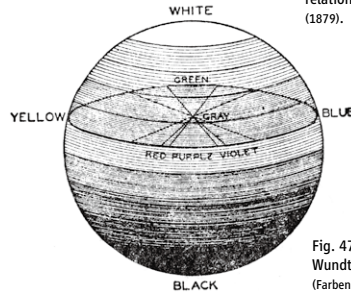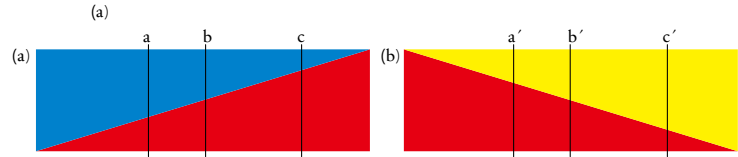Fig. 47: Psychologist Wundt's color sphere (Farbenkugel).
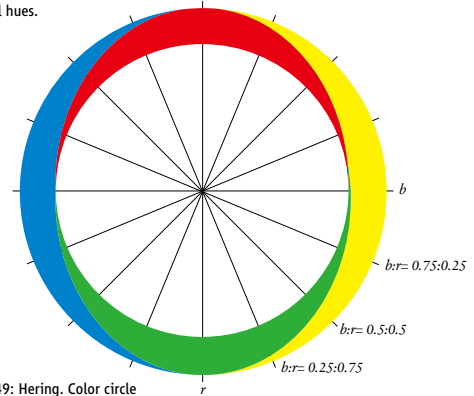
Fig. 49: Hering. Color circle created from four color crescents.

b:r= 0.75:0.25
b:r= 0.5:0.5
b:r= 0.25:0.75

were all reported to be fascinated by this book.

Rood was also an advisor to color researcher Munsell. Rood's practical systemization of color formed an essential part of Munsell's later work.
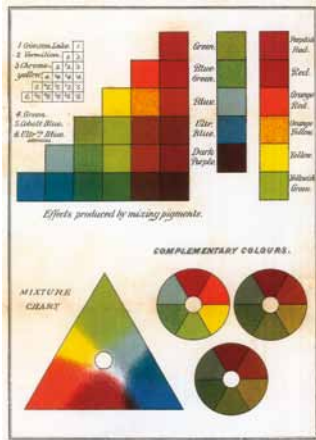
Fig. 46: Rood. (Upper) Pigment mixing. (Lower) Light mixing complementary color circle (1879)

Fig. 50: Hering's color circle.

Color circles modeled on flower petals

Attempts at creating new color palettes

Charles Hayter
1761–1835,
England

Charles Blanc
1813–1882,
France

Charles Lacouture
1832–1908,
France

Michel Jacobs
1877–1958,
Canada

Hayter's color circle

Portrait artist and architect, Charles Hayter in 1830 published a work entitled *A New Practical Treatise on the Primitive Colours* covering rules for creating various colors by mixing colors. This volume contains a number of fascinating colored diagrams, but the main color system diagram (Fig. 51) placed at the beginning of the book strangely lacks colors. This may be due to the difficulties posed by working with large numbers of colors. The three primary colors in Hayter's petal-arrangement diagram are the same yellow, red, and blue proposed by Leonardo da Vinci. The three secondary colors are orange, green, and purple. The tertiary colors are olive, brown, and slate gray (bluish gray); he uses slate gray with several varying hues in a number of places. Hayter does not appear to distinguish between additive color mixtures and subtractive color mixtures.

Charles Blanc's color circle

Art critic and historian Charles Blanc included the "Chromatic Rose" color circle shown in Fig. 52, representing a flower, in his manual entitled *Grammaire des Arts du Dessin*. This book introduced Chevreul's color theory to various neo-impressionists, including Seurat.

Lacouture's color circle

In 1890, French botanist and naturalist Charles Lacouture in Paris published *Répertoire Chromatique*. In addition to books on color, Lacouture was a high school teacher and the author of works on moss and flowerless plants. Lacouture's *Répertoire Chromatique* included a color chart (Fig. 53) called the trilobe synoptique for analyzing color mixtures. As suggested by the name, colors are arranged in the pattern of three leaves. The red, blue, and yellow on the periphery form the three primary colors, forming arcs from these starting points. Colors vary gradually in six gradations toward the periphery, starting from white at the origin. Red becomes R1, R2, and R3, a system that can perhaps be described as the invention of the color chart. Color charts are typically square grids, but this chart was devised with a unique design right from the start.

Jacobs' color circle

In 1923, Canadian-born sculptor and artist Michel Jacobs wrote the book *The Art of Color*, in which he refers to the psychological effects of color arrangement and proposes unique theories on color harmony. Jacobs was a proponent of the Young-Helmholtz theory and used the three primary colors red, green, and purple, which he referred to as the spectral primary colors. The purple used by Jacobs was actually the blue-violet color used by both Bezold and Hemholtz.

Let us examine Jacobs' color circle (Fig. 55). The spectral primary colors mentioned above are arranged on a circle, with the three secondary colors yellow, blue, and carmine red arranged in opposing positions from the center. Three complementary color pairs are therefore created by the spectral primary colors and secondary colors. The color circle positions are arranged with opposing convex and concave curves, forming complementary color pairs that create six possible mixed colors. Jacobs described the configuration of his color circle as an open garland, and it featured orange, yellow-green, blue-green, blue-violet, purple, and scarlet, proceeding clockwise. Complementary color pairs formed a single flow, such as purple and yellow-green. The numerous lines drawn on the three garlands separate the complementary colors and alleviate the contrast. Jacobs used the term spectral primary colors, but his color circle ultimately addressed pigment subtractive color mixtures.
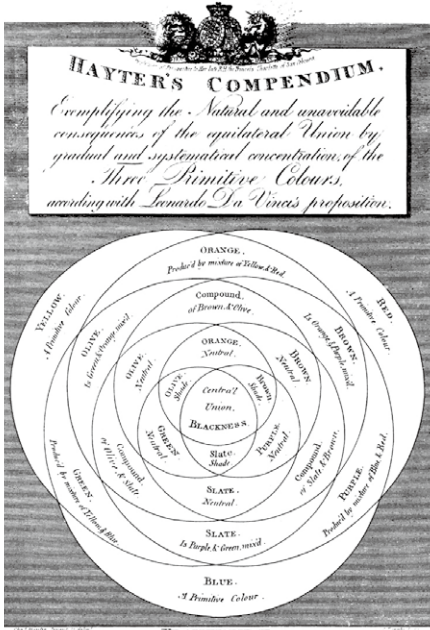
Color Circles Shown in Diagrams- 8

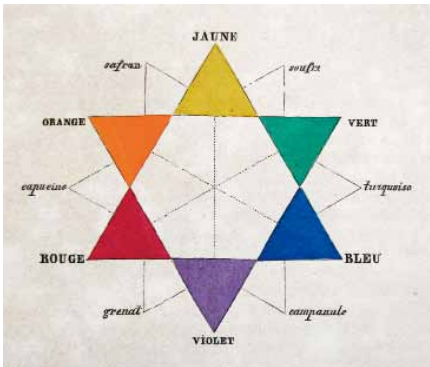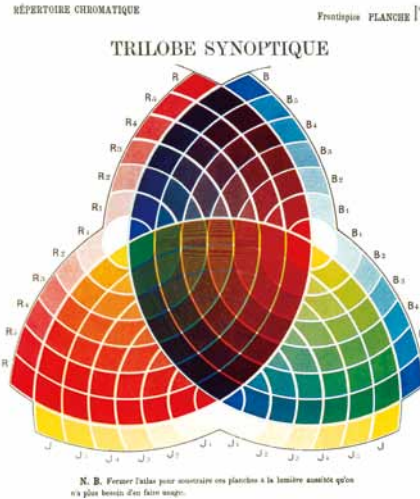

Fig. 51: Hayter's color circle (1830).

Fig. 53: Blue, red, and yellow *Trilobe Synoptique* mixed color chart devised by Lacouture.

Fig. 55: Michel Jacobs, 1923.

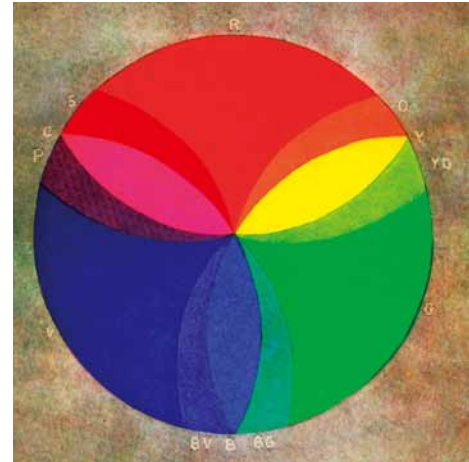Fig. 52: Painting Compas (partial).

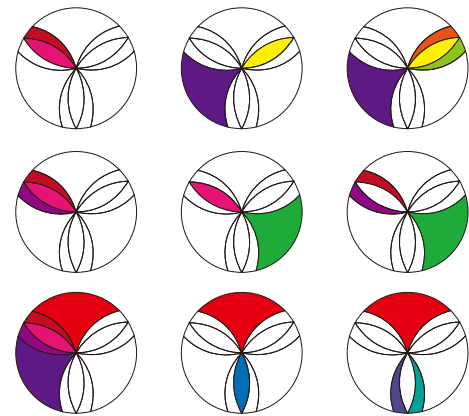Fig. 54: Lacouture's color circle titled "Rosesynoptique".

Fig. 56: Combination of harmonies.

Bauhaus and color circles

The quest for color harmony in design

The teaching of color at the Bauhaus represented an aesthetic study of, and research into 18th century theories of color, with a curriculum incorporating the harmony theories of color and sound developed by Newton.

Outside their classes, Johannes Itten, Wassily Kandinsky, and Paul Klee undertook numerous visualization experiments related to shape, color, and tone.

Paul Klee
1879–1940,
Germany

Johannes Itten
1888–1967,
Germany

Fig. 57: "Canon of totality" of color.
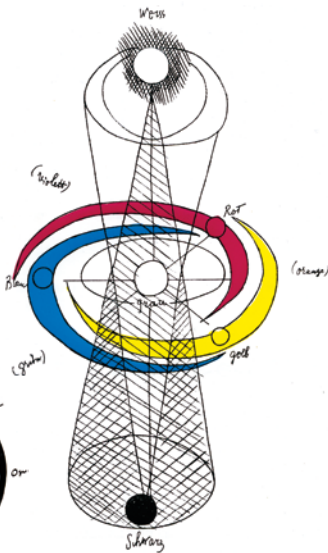
Fig. 58: Paul Klee's "Canon of color totality" diagram.

Itten's color circle

The ethos and methods of Johannes Itten, a leading lecturer on color from 1920 at the Bauhaus, the pinnacle of design education, remain valid to this day. The large number of color frameworks he taught were analyzed using color perception beyond the fundamentals of color, providing the optimum materials for the fundamentals of design teaching. (See Fig. 59, 61, 62, and 63) Itten studied under Adolf Hölzel in Stuttgart, learning all of the color theories, including those of Runge, Goethe, Chevreul, Ostwald, Schopenhauer, and Schreiber. He went on to collate these classical color theories in his initial experiments. Itten's color circle can be described as one of the most famous of all color circles, invariably featured in textbooks on color. Together with the 12-color circle (Fig. 61), the famous color star (Fig. 62) was a two-dimensional version of Runge's color sphere (Fig. 29). The most famous aspect of Itten's color theory is his color harmony theory, incorporating triads and tetrads, but this had already been proposed by Chevreul. This idea was analogous to the horoscope diagrams widely used in the West, such as those devised by Ptolemy (Fig. 60), Galileo, and Comenius.

During his period at the Bauhaus from 1919 to 1923, Itten established a personal studio inside the Knights Templar gothic-style building designed by Goethe in a park in Weimar. The mystic nuances noticeable in Itten's work have clear origins in these surroundings.

Itten resigned abruptly from the Bauhaus in October 1922 following disagreements with the director, Gropius, and color teaching duties passed to Paul Klee.

Klee's formative theories and color circle

Paul Klee was the successor to Itten, taking over as professor of color teaching at the Bauhaus from 1923 onward. He, too, has left a number of color circle ideas within his own formative theories, which we will examine here.

The details of Klee's teachings on color are covered extensively in his various works, such as *Das Bildnerische Denken and Beitra zur bildnerischen Formlehre* (The Thinking Eye: The Notebook of Paul Klee). Perhaps no writer left as much detailed information on his thought processes with regard to color as Klee. His five-sided mysterious palette (Fig. 65) also indicates his thoughts on pigment color mixtures. He also produced diagrams depicting harmonies of color and sound.

A characteristic of Klee's diagrams is the provision of dynamic laws of motion in which opposing colors are linked by gradations, with emphasis placed on middle gray.

This is a characteristic shared by Itten's diagrams, which also reflect significant influence from classicists such as Plato, Aristotle, Robert Fludd, and Athanasius Kircher, as well as Runge and Goethe. Fludd and Kircher expressed universal mysticism using various diagrams. However, Klee's "Canon of color totality" diagram (Fig. 58) brings to mind Aristotle's theory of light and dark. The bottommost part consists of darkness; the topmost area is light. The three primary colors of red, blue, and yellow rotate on a plane around the center. Klee described this arrangement as a "canon" of color. The individual colors vary in width and overlap, creating various intermediate colors (as in Hering's idea). The diagram appears at first glance to be meaningless from a chromatic viewpoint, but it expresses past color theories in a geometric format filtered through an artist's sensibility.

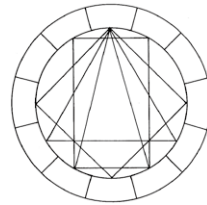# Color Circles Shown in Diagrams- 9

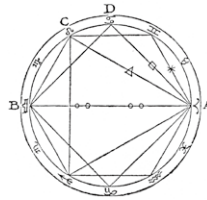Fig. 59: Johannes Itten's color harmony theory diagram

Fig. 60: From the Latin version of Ptolemy's *Harmony*

Fig. 64: Klee's three-primary color diagram

⬆ Fig. 61: 12 color circles. Color circles developed from the primary colors of yellow, red, blue, orange, green, and violet.

⬅ Fig. 62: Itten's 12-coordinate color star. Each hue has two gradations from the midway pure color to the center and two gradations to black at the periphery.

➡ Fig. 63: Itten's color solid. Diagram recreatiung Runge's color sphere for teaching color theory. The two at the top are the color solid surfaces, and the bottom left is the horizontal cross section at the equatorial pure color plane. The bottom right shows the vertical cross section through blue and green.
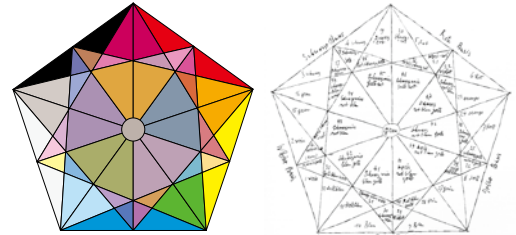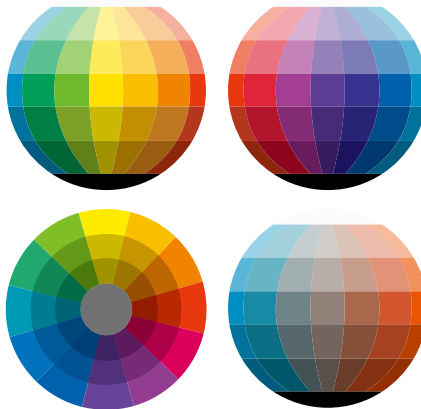
Fig. 65: "Basic star shape color plane and compound star" by Paul Klee. Various extreme cases with common equilibrium points connected by gray.

The birth of practical color systems

The quest for an international color standard
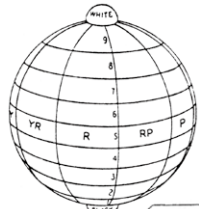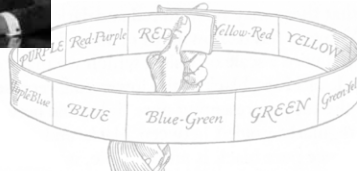

Munsell also first considered spherical arrangements. (1905)
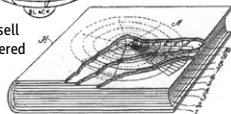
The color circle patented by Munsell in 1906 had the seven Newtonian colors of red, orange, yellow, green, blue, indigo, and violet. His concept using 10 colors appeared later.
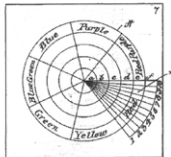
Wilhelm F. Ostwald 1853–1932, Germany

Albert H. Munsell 1858–1918 USA

Ostwald's "abacus bead" shape color system

A multi-talented scientist, Wilhelm Ostwald won the Nobel Prize for his research on catalysts and chemical reactions. In his later years, he devoted his time to color research, devising his own color system and proposing a color arrangement method based on the principle: "Harmony Equals Order." Ostwald's color system was based on the four primary colors used by Hering, and he designed a grayscale using the Weber–Fechner Law governing the relationship between perception and stimulation. Triangular planes of identical hue are formed by pure colors (full colors), white, and black at each apex, and 24 of these hue planes are arranged in a double cone to create an abacus bead shape. Ostwald's color system was improved in the 1950s to become part of the DIN (German Institute for Standardization) system and was absorbed in similar form in the 1970s into the NCS Natural Color System.

Albert Munsell's color system

An American art teacher, Albert Henry Munsell in 1905 published *A Color Notation*, which provided a means of expressing all colors in terms of the three characteristics of color: hue, value, and chroma.

His color solid created using these three characteristics was based on a central vertical axis for lightness in 10 steps from white (0) to black (10), and with 10 hues arranged at even intervals around the circumference. The final version differed from the original following improvements, becoming a somewhat awkward shape. This is because the maximum chroma values for each hue vary between 10 and 15, resulting when viewed from above in the uneven arrangement shown in Fig. 71.

Munsell sought to explain color simply, using a wide range of illustrations, such as globes or tangerine oranges to explain his ideas. The diagrams used in his works alone would no doubt be enough to form a single book. While the current Munsell color diagram uses 10 color hues, the diagrams in the 1906 patent application featured Newton's seven hues. The Munsell color system is explained in greater detail on pages 30 to 31.

NCS color system

The NCS (Natural Color System) is a color system used in the Swedish industrial standards. The NCS color system expresses colors in terms of constituent ratios of six psychological elementary colors: white, black, red, yellow, green, and blue. The colors are divided into 10 even steps between the primary colors red, yellow, green, and blue, giving 40 hues. The shape of the color solid resembles the abacus bead shape of Ostwald's color solid, but a major difference is that the colors making up the solid are determined based on perceptive (psychological) experimental data.

Academic journals and catalogs:

Charles Parkhurst and Robert L. Feller, Who Invented the Color Wheel?, *Color Research and Application*, Vol.7 Number 3, 1982.
Sven Hesselgren, Why Color Order Systems?, *Color Research and Application*, Vol.9 Number 4, 1984.
Mitsuo Kobayashi, The 34th Annual Meeting of the Color Science Association of Japan (2003), Abstract.
Koji Ogata, Chromatics; Chromatography; Color Theory: *Chromatics* (contained in Catalog of Western Rare Books at Bunka Women's University Library).

Books:

Akira Kitabatake, *Key Works and Illustrations in Chromatics* (Yushodo).
Klaus Stromer, *Color Systems in Art and Science*; Traditions and Colors (Golden); *Farbsysteme* (Dumont).
Rolf G. Kuehini, *Color Space* (Wiley-Interscience).
Frans Gerritsen, *Modern Color* (Bijutsu Shuppan-sha); *Evolution in Color* (Schiffer Publishing, 1988).
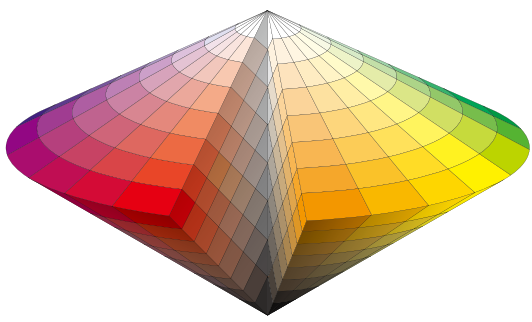
Color Circles Shown in Diagrams- 10

Fig. 68: Ostwald's abacus bead shape color solid
Fig. 69: Ostwald's 24-color circle

Fig. 70: View from above the model published by Munsell in 1915. (20 hues)
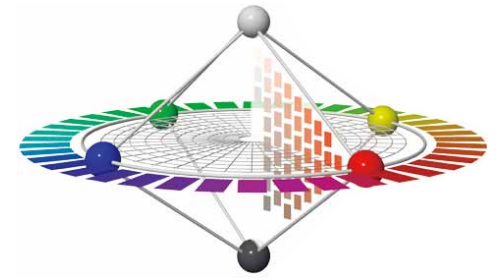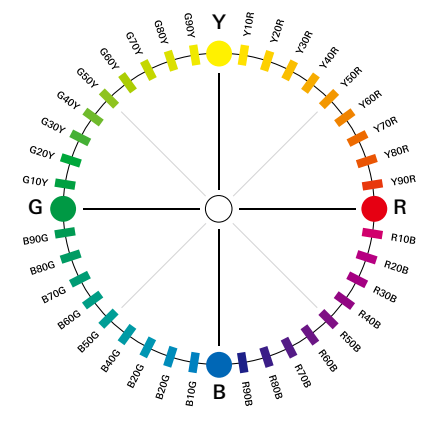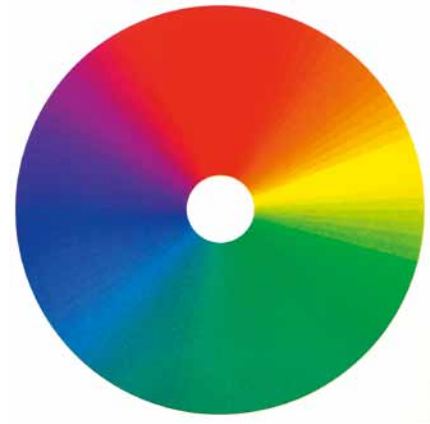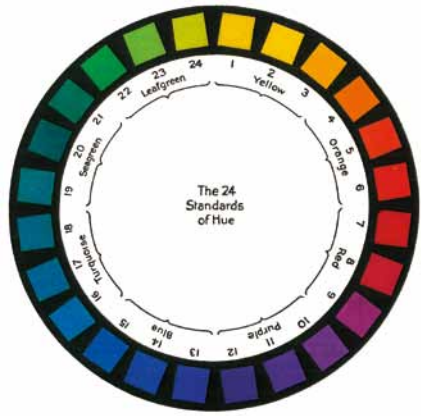Fig. 71: Munsell's 100-hue circle

Fig. 72: Swedish industrial standard NCS color solid model
Fig. 73: NCS 40-hue (1979)

Yxy-CIE chromacity diagram

The Yxy color space allows color to be expressed graphically in two dimensions independent of intensity. Plotting the wavelengths of the visible spectrum converted into x-y chromacity coordinates produces the horseshoe curve known as the spectral locus (pure color light locus/lower diagram, left). All colors visible to the human eye can be plotted within this curve.

Colors have been added to the x-y chromacity diagram on the right for clarity, but some chromatics text books recommend not adding color to the chromacity diagram. The hue along the periphery of the horseshoe varies in the spectral order discovered by Newton. The straight line connecting the two ends of the horseshoe curve is known as the purple boundary. Colors located on this line consist of a mixture of 380 nm (violet) and 770 nm (red) light and are not contained in the solar spectrum.
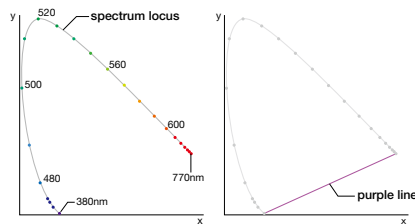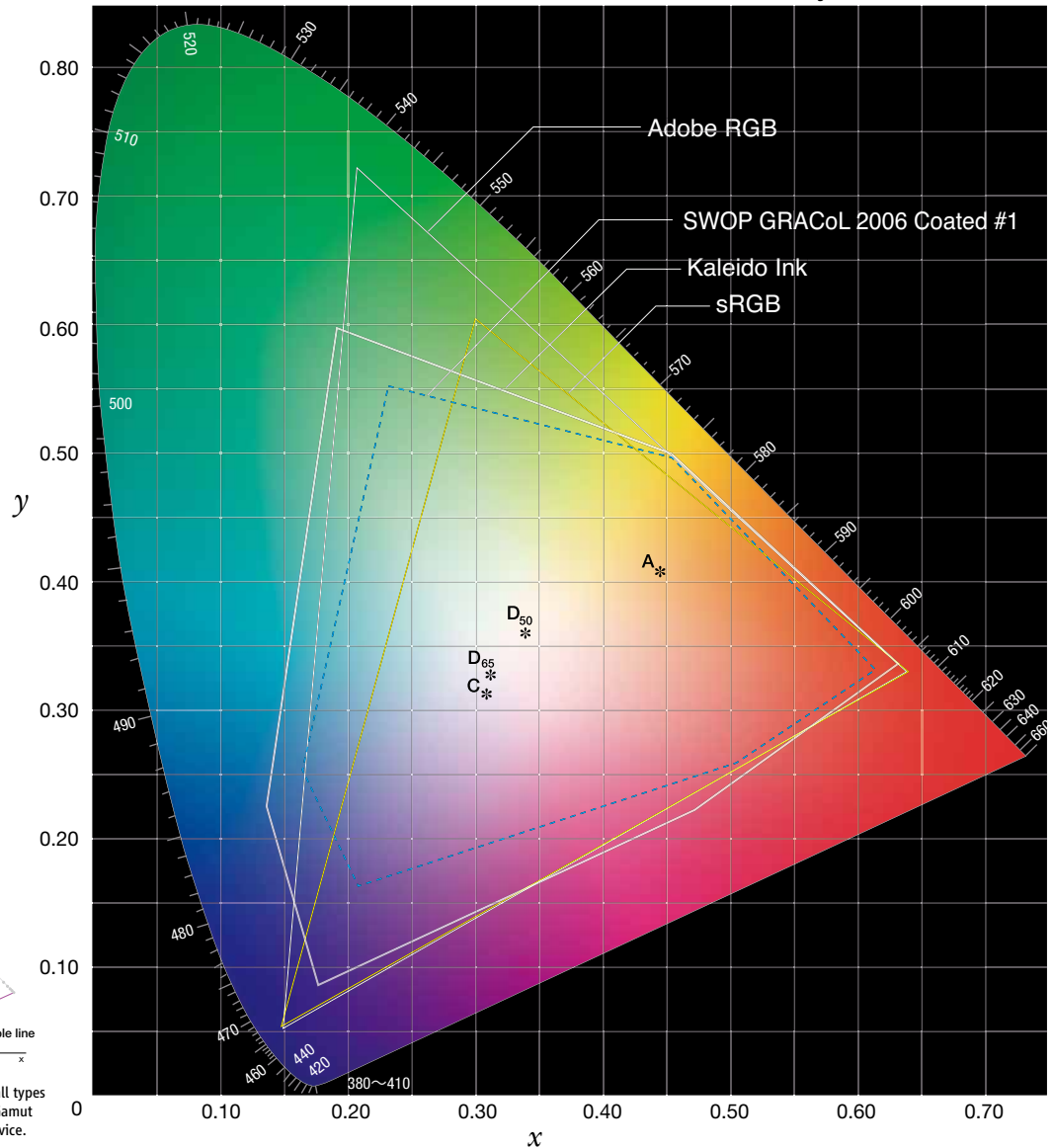

Fig. 74: The xy color chart enables gamut to be plotted for all types of tristimulus value devices such as monitors and printers. Gamut refers to the range of colors that can be displayed by the device.

Fig. 75: CIE 1931 (*xy* chromacity diagram).

CIE LAB
Color space

CIELAB color space is a uniform color space recommended in 1976 by the International Commission on Illumination (CIE), written as CIE *L*a*b**. This color space (Fig. 76) is relatively uniform perceptually and conforms closely to the red-green and blue-yellow scales. CIELAB is widely used in areas involving reflective and transparent products, such as printing and graphic arts. Adobe Photoshop, for example, uses CIELAB as the internal color space for calculation processing. (Refer to page 41 ΔE: Color differences.)
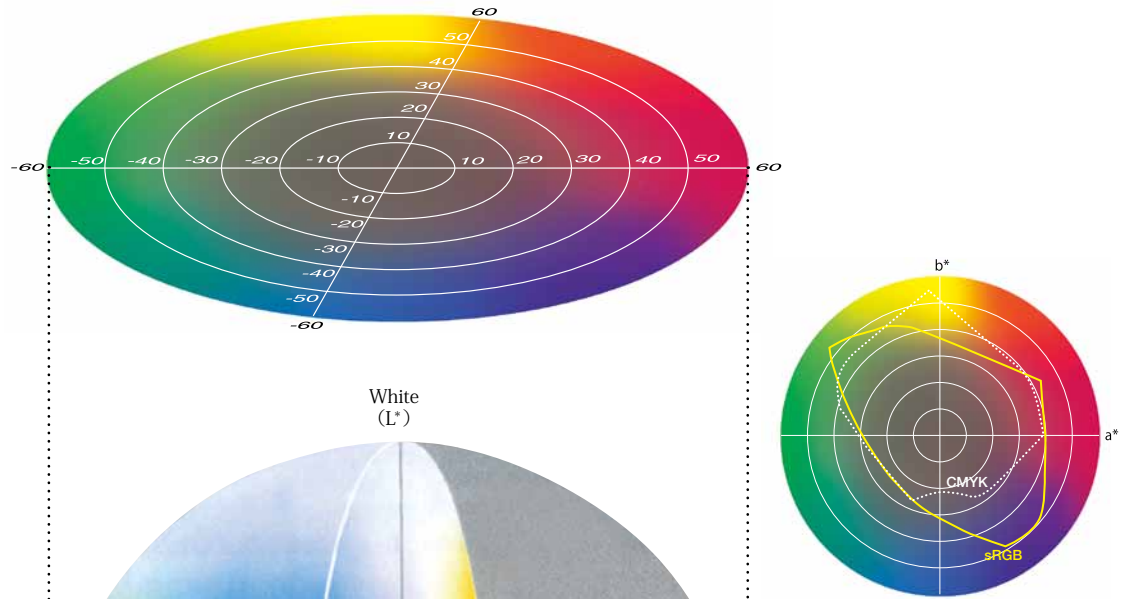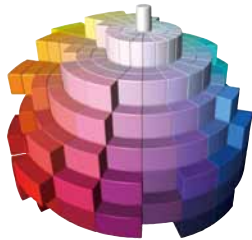

b*

a*
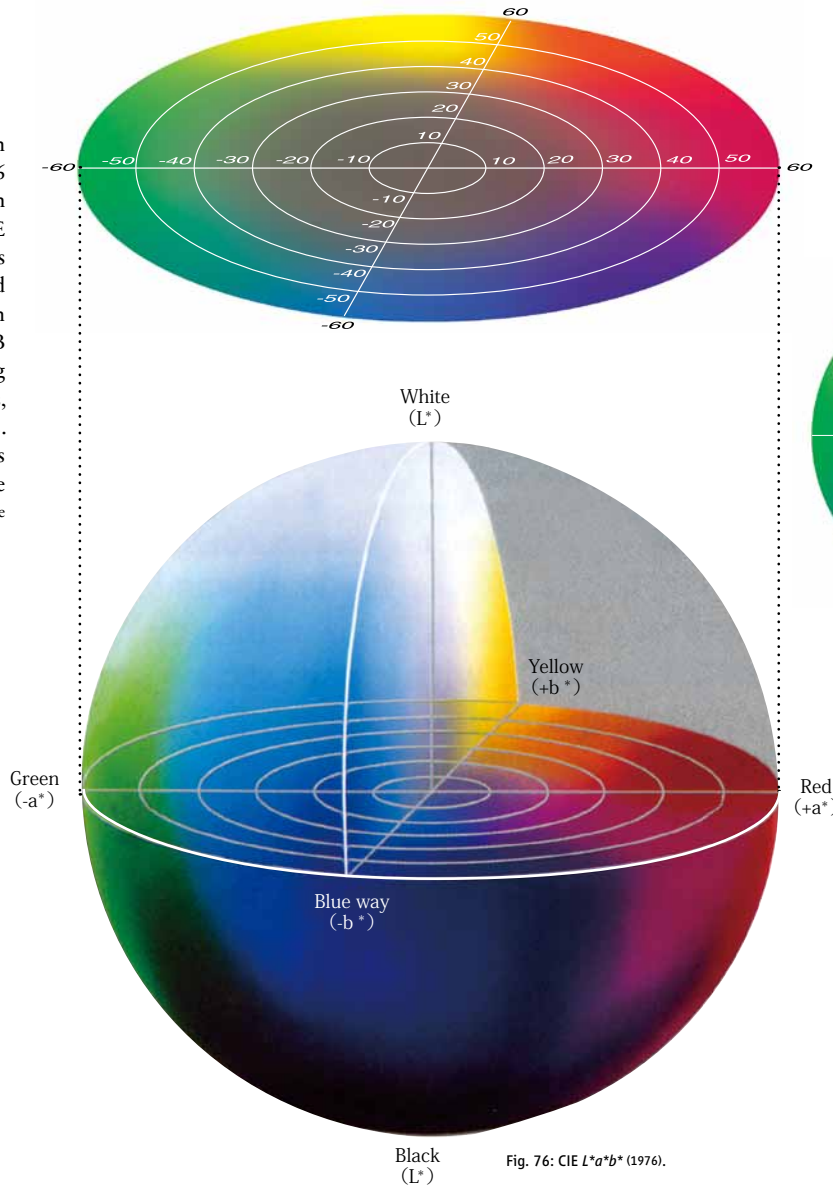
CMYK

sRGB

Fig. 77: The upper graph plots the CMYK and sRGB color ranges on the horizontal cross section of the Lab central portion.

White
(L*)

Yellow
(+b*)

Green
(-a*)

Red
(+a*)

Blue way
(-b*)

Black
(L*)

Fig. 76: CIE *L*a*b** (1976).

Modified Munsell color system

From visual appreciation to digitalization

Munsell notation

As mentioned earlier, Albert. H. Munsell (1858-1918) was an American art teacher who published A Color Notation in 1905, a system that made it possible to describe real colors in terms of three color characteristics.

This color system was based on integers of 10. The color wheel was divided into ten using the five main Munsell hues (red, yellow, green, blue, and purple) and five intermediate hues (yellow-red, green-yellow, blue-green, purple-blue, and red-purple), with all hues identified by names.

The center of the circle has a vertical bar with 0 (black) at the bottom and 10 (white) at the top and achromatic grays in between. This forms the Munsell value (lightness) scale. The distance from the center axis to the periphery is divided perceptually into even gradations, starting at 0 at the center. This distance expresses the Munsell chroma (saturation) for a specific hue. Munsell's color system was initially illustrated as a spherical diagram, but was designed so that differences between all colors appear uniform. (See Fig. 78)

Colors are specified in Munsell notation in the form of hue followed by lightness, with chroma indicated

after a slash. For example, "5R8/4" indicates a red hue, fairly light, with moderate saturation. In other words, pink. Similarly, "5P3/8" indicates a purple hue, quite dark, but with high saturation: in other words, a grape-like color.

As can be seen from Fig. 79 on the right-hand page, the maximum chroma varies according to hue. The solid used to express perceived colors therefore becomes an uneven shape rather than a balanced sphere.

Modified Munsell color system

Munsell's color space is formed of perceptually uniform color divisions. However, advances in color measurement technology in the 20th century led to the establishment of the XYZ color system in 1931, and Judd and a number of other researchers examined the color chart in the Munsell Book of Color in detail to correct a number of discrepancies and achieve compatibility between the Munsell system and the XYZ color system. This was the Munsell hue locus correspondence diagram for the x-y chromacity diagram, shown in Fig. 78 to the left. Thus, the Munsell system was reborn in 1943 as the Munsell Renotation System. This has now entered widespread use, and the "Renotation" is often dropped.
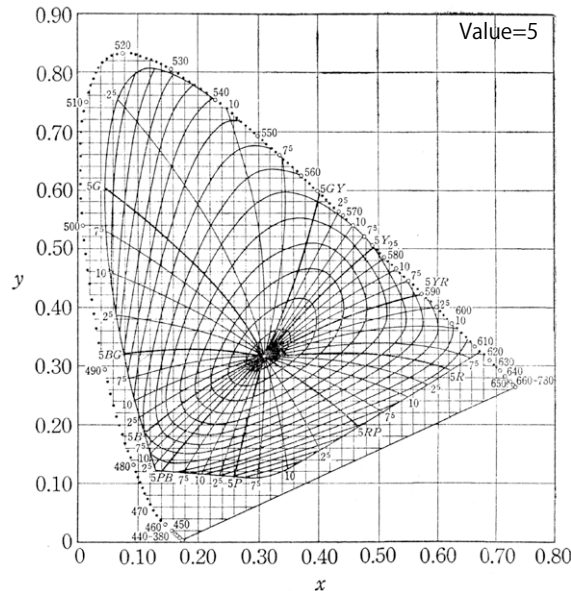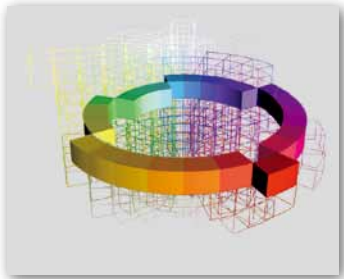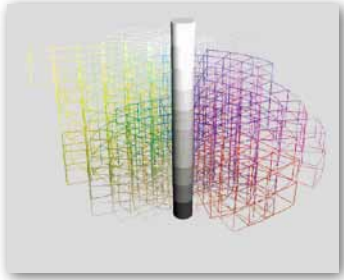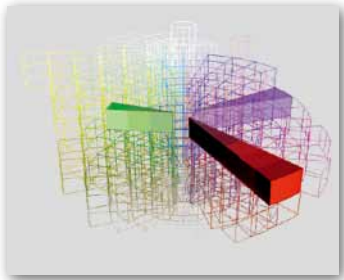

Fig. 78: Produced by Color Measurement Laboratory, War Food Administration, U.S.D.A.

Hue

Value

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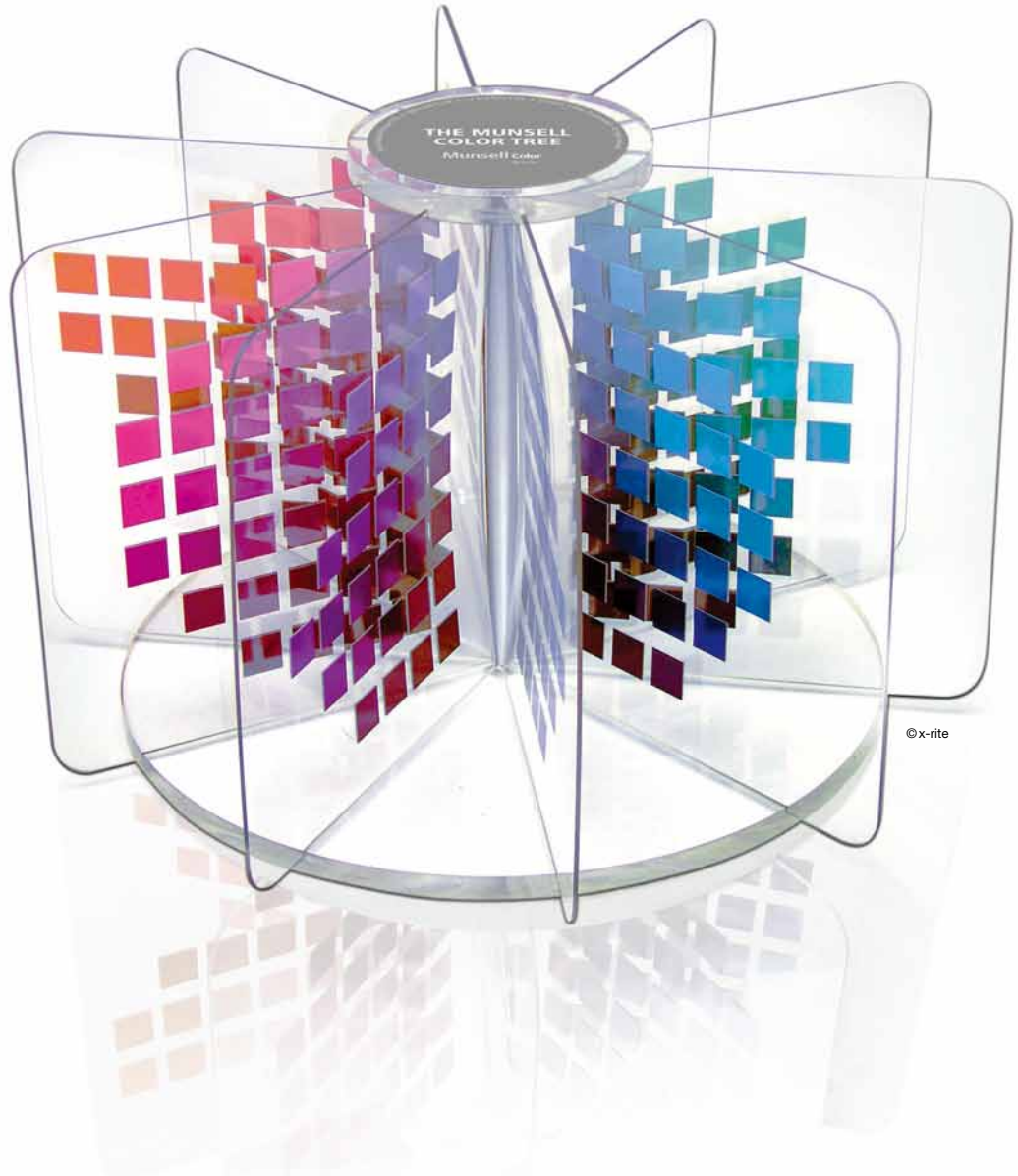
Chroma

Fig. 79: Munsell's three-characteristic explanation.

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