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Color Order Systems

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Synonyms

[Color atlases](#); [Color models](#); [Color solids](#); [Color spaces](#)

Definitions

- (a) A system for categorizing colors. An arrangement of color perceptions, color stimuli, or material color samples according to certain rules
- (b) A subset of the world of color according to three attributes that constitute the coordinates of the color system
- (c) A rational plan for ordering and specifying all object colors by a set of material standards

Color System Review and Evaluation

The aim of making order in the vast set of colors that humans are able to distinguish has existed since the ancient times and appears along the whole human history. Among the people who have proposed some kind of color order systems, there are famous philosophers, architects, artists, scientists, and writers, for instance, ► [Aristotle](#) (c.350 BC), Leon B. Alberti (1435), Leonardo da Vinci (1516), Isaac Newton (1704), and Johann W. Goethe (1810). In the twentieth century, other scientists and theorists, such as Albert H. Munsell (1905, 1907, 1915), Wilhelm Ostwald (1916, 1917), Arthur Pope (1922, 1929, 1949), Cándido Villalobos and Julio Villalobos-Domínguez (1947), Antal Nemcsics (1975), Harald Küppers (1978), and Frans Gerritsen (1987), just to mention a few, have been outstanding in formulating and building color order systems. This endeavor has also been pursued by organizations such as the Commission Internationale de l'Eclairage (1931, 1976), the Optical Society of America (1947–1977), the Swedish Standards Institution (1979), and others.

A color order system seeks to include all colors in a topological model, giving a specific position to each color and proposing some kind of logic that determines the whole organization. These models have adopted, according to the different authors and along times, the most diverse shapes: linear scales, chromatic circles, color triangles, and color solids. Within this last type, different solutions have been offered: cones, pyramids, double cones, double pyramids, spheres, and more or less irregular solids.

Old Linear Organizations and Two-Dimensional Diagrams

The most ancient color organizations are often simple lists of color names, linear scales – generally expressed in verbal form, without graphic representations – or two-dimensional diagrams in the form of color triangles or circles. Among the first group, two can be mentioned: the five colors of the old Chinese

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philosophy (blue, red, yellow, white, and black), related to the five elements (wood, fire, earth, metal, and water) and to the five metaphysical localizations (east, south, center, west, and north), and the color scale of ► [Aristotle](#) (born 384 BC – died 322 BC), with white and black at the ends and a series of intermediate chromatic colors linearly arranged between these two extremes of light and darkness. A verbal ordering of colors, which some authors reconstruct as a chromatic circle or a square, and even as a double cone, a double pyramid, or a sphere [1], is found in the book by Leon Battista Alberti (born 1404 – died 1472), *On Painting*.

A great deal of the *Treatise on painting* by Leonardo da Vinci (born 1452 – died 1519), compiled after his death from his notebooks, is dedicated to insights about color. For the arrangement of colors, he proposes a simple scheme based on the oppositions black-white, blue-yellow, and green-red.

The Belgian Jesuit Franciscus Aguilonius (born 1567 – died 1617) published his *Opticorum libri sex* in 1613 in Antwerp, and the German Jesuit Athanasius Kircher (born 1602 – died 1680) published his *Ars magna lucis et umbrae* in 1646 in Rome. Both texts include diagrams with the arrangement and mixing of colors.

Aron Sigfrid Forsius (born 1550 – died 1624), a Finnish-born clergyman, cartographer, and astronomer who worked in Sweden, wrote a manuscript in 1611 where the first-known drawing of a ► [color circle](#) appears. Forsius' circle presents the following sequence: white, yellow, red, brown, black, green, blue, and gray, closing again in white. Forsius characterizes this circle as “ancient” and draws an alternative for the arrangement of colors. Various theorists have interpreted this second diagram as a sphere. If this can be demonstrated, it would be the first three-dimensional system in the history of color.

Isaac Newton (born 1642 – died 1727) discriminated seven colors in the spectrum produced by the dispersion of light through a prism and arranged them in the perimeter of a circle divided into seven portions, with the center occupied by the white light. While the chromatic circle of Newton responds to the additive mixture of lights, the circle devised by Johann Wolfgang von Goethe (born 1749 – died 1832), in his *Theory of Colors* published in 1810, responds to the subtractive mixture of pigments. Three ► [primary colors](#) – red, yellow, and blue – appear at the vertices of an equilateral triangle, opposed to another equilateral triangle with three secondary hues – orange, green, and purple – product of the subtractive mixture of the former.

Two Important Three-Dimensional Systems Before the Twentieth Century

By 1772, the first color solid expressly developed and drawn as such by its author, Johann Heinrich Lambert (born 1728 – died 1777), appears. The pyramid has a triangle with scarlet (equivalent to the red primary), amber (equivalent to the yellow primary), and blue at its base, from whose mixtures Lambert is able to obtain black in the center of the triangle at the base. Hence, this is an arrangement of subtractive mixture of pigments. By placing white in the upper vertex, the system is completed.

The German painter Philip Otto Runge (born 1777 – died 1810) built a color sphere that is considered the ancestor of most of the twentieth-century color systems and could be termed “modern” for this. Runge's sphere, published in 1810, is the significant result of a sustained evolutionary process initiated in the Renaissance. The chromatic circle, at the equator of the sphere, is arranged on the basis of the red-yellow-blue triad of primaries, plus the green-orange-violet triad of secondaries, as in Goethe's circle.

Classification of Color Order Systems

Color systems can be categorized in two large groups: color stimulus systems and color perception systems. Color stimulus systems are established in the twentieth and twenty-first centuries. Their developers are almost without exception physicists and information specialists. They are systematizing

radiation energy of different wavelengths creating the experience of different colors. These have been registered for the industry in international standards. Their detailed description may be found in chapters of the Encyclopedia dealing with the measurement of color and computerized displaying of color.

The roots of the establishment of color perception systems appear in the distant past. Their creators are representatives of the most different professions. There are, among others, painter artists, architects, writers, poets, philosophers, doctors, priests, bishops, chemists, botanists, and many other crafts being charmed by the diversified world of colors.

The established multitude of perception-based color systems can be categorized into eight groups in terms of aims, classification methods, and definition of color patterns by color notation. Irrespective of their categorization, they possess numerous identical attributes.

Every perception-based color system possesses a color atlas containing color samples. At the beginning, colors have been located onto planes, within a triangle, square, or circle region. Later, in the seventeenth century, it turned out that the multitude of colors can be arranged only within a three-dimensional space. With the exception of two systems (Munsell, Coloroid), colors were arranged on the surface of or within regular bodies. The most frequently applied bodies were the following: a triangle-based cone (Lambert system), a triangle-based prism (Mayer system), a circle-based double cone (Ostwald system [2]), a square-based double cone (Höfler system), a circle-based truncated cone (Baumann-Prase system), a cube (Hickethier system), a globe (Runge system), a semiglobe (Chevreul system), a body of rotation consisting of cones (Wilson system), a circle-based cylinder (Frieling system), and a body constructed of cubo-octahedrons (OSA system).

The irregular shapes of the color bodies of Munsell and Coloroid color systems were the result of the fact that, as opposed to the other color systems, they have taken into account the magnitude of saturation and luminance of colors of different hues distinguishable by humans.

All perception-based color systems are discontinuous, the single exception being the Coloroid system. They contain only a definite number of colors from the color space. In most of the systems, the letter or number notating the color indicates the location of the color in the color atlas. In most of the systems, the color notation gives the additive or subtractive components for color mixing. In some systems, it defines a particular color perception. In the case of some color systems (e.g., Munsell, NCS), the color coordinates of the CIEXYZ color system have been linked to a definite number of their colors. It allows the calculation of CIE coordinates – by interpolations with different degrees of inaccuracy – also for colors not presented in the color atlas. A direct transformation relation exists only between Coloroid and CIEXYZ which enables defining with equal accuracy in both systems all colors distinguishable by the human eye, i.e., more than a million colors.

Review List of Ancient and Modern Color Order Systems

Systems of Color Stimuli

Device-Independent Systems

Schrödinger 1920, Luther 1924, Nyberg 1928, Rösch 1928, Wright 1928, Guild 1931, CIEXYZ 1931, MacAdam 1942, Stiles 1946, Brown 1951, CIE 1960, Wyszecki 1963, CIE 1964, Judd 1963, CIELAB 1976, CIELUV 1976, CIECAM 1997, CIECAM 2002.

Device-Dependent Systems

RGB 1983, HLS 1983, HSV 1983, CMY 1983, CMYK 1983, Adobe RGB 1998, sRGB, HKS, HSV.

Systems of Color Sensations

Visual Systems Based on Experience

Grosseteste 1230, Alberti 1435, Leonardo da Vinci 1516, Forsius 1611, Aguilonius 1613, Fludd 1629, Boutet 1708, Harris 1766, Schiffermüller 1772, Baumgärtner 1803, Runge 1810, Hay 1828, Merimée 1839, Field 1846, Barnard 1855, Delacroix 1856, Jannicke 1978, Henry 1889, Kreevitzer 1894, Pope 1922, Becke 1924.

Systems Based on Music Parallelism

Newton 1704, Adams 1862, Seurat 1887.

Systems Based on Additive Color Mixing

Wünsch 1792, Chevreul 1839, Grassmann 1853, Maxwell 1855, Helmholtz 1860, Bezold 1874, Vanderpoel 1902, Ridgway 1913, Ostwald 1916, Baumann-Prase 1941, Jacobson 1948, Rabkin 1950.

Systems Based on Subtractive Color Mixing

Kircher 1646, Waller 1686, Mayer 1778, Sowerby 1809, Hayter 1826, Benson 1868, Hering 1878, Rood 1879, Lovibond 1887, Lacouture 1890, Höfler 1897, Plochère 1946, Colorizer 1947, Müller 1948.

Printed Screen Systems

Wilson 1942, Villalobos 1947, Hickethier 1963, Küppers 1978.

Educational Systems Based on Psychological Effects

Goethe 1810, Schopenhauer 1830, Wundt 1874, Ebbinghaus 1902, Klee 1922, Itten 1923, Boring 1929, Birren 1934, Frieling 1968, CMM Silvestrini 1986, Gerritsen 1987, Albert-Vanel 1990.

Perceptually Equidistant Color Systems

Munsell 1905, Johansson 1937, DIN-Richter 1953, Hesselgreen 1953, OSA-Wyszecki 1960, Manfred Adam 1966, Kobayashi 1966, Coloroid-Nemcsics 1975, Acoat Color Codification, NCS (Hård, Sivik, Tonnquist) 1979, Eusemann 1979, Chromaton 1981.

Practical Color Collections

Maerz 1930, Jeanneret 1937, ISCC-Kelly 1955, Gericke-Schöne 1969, Chroma Cosmos 1987, Master Atlas 1988, Cler 1992, RAL 1993, Pantone, EuroColor 1984.

Color Systems Used Today, Recommended for Art and Design

Munsell Color System

The foundations for the most up-to-date idea of color systems were first laid down by Munsell, who published his *Book of Color* [3] and the pertinent color sample collection in 1915 for the first time. This system has been further developed in 1943 and correlated to the CIE 1931 colorimetry system. In 1956, it was extended to include very dark colors. Later, the Munsell Color Company was founded for re-editing at regular intervals, in the original quality, the color collection of the system. Since 1979, it is also published in Japan under the title Chroma Cosmos 5000.

The Munsell system is still one of the most popular color systems. Its codes are up to this day the most common color identification numbers in the international literature. Colors are identified by three data:

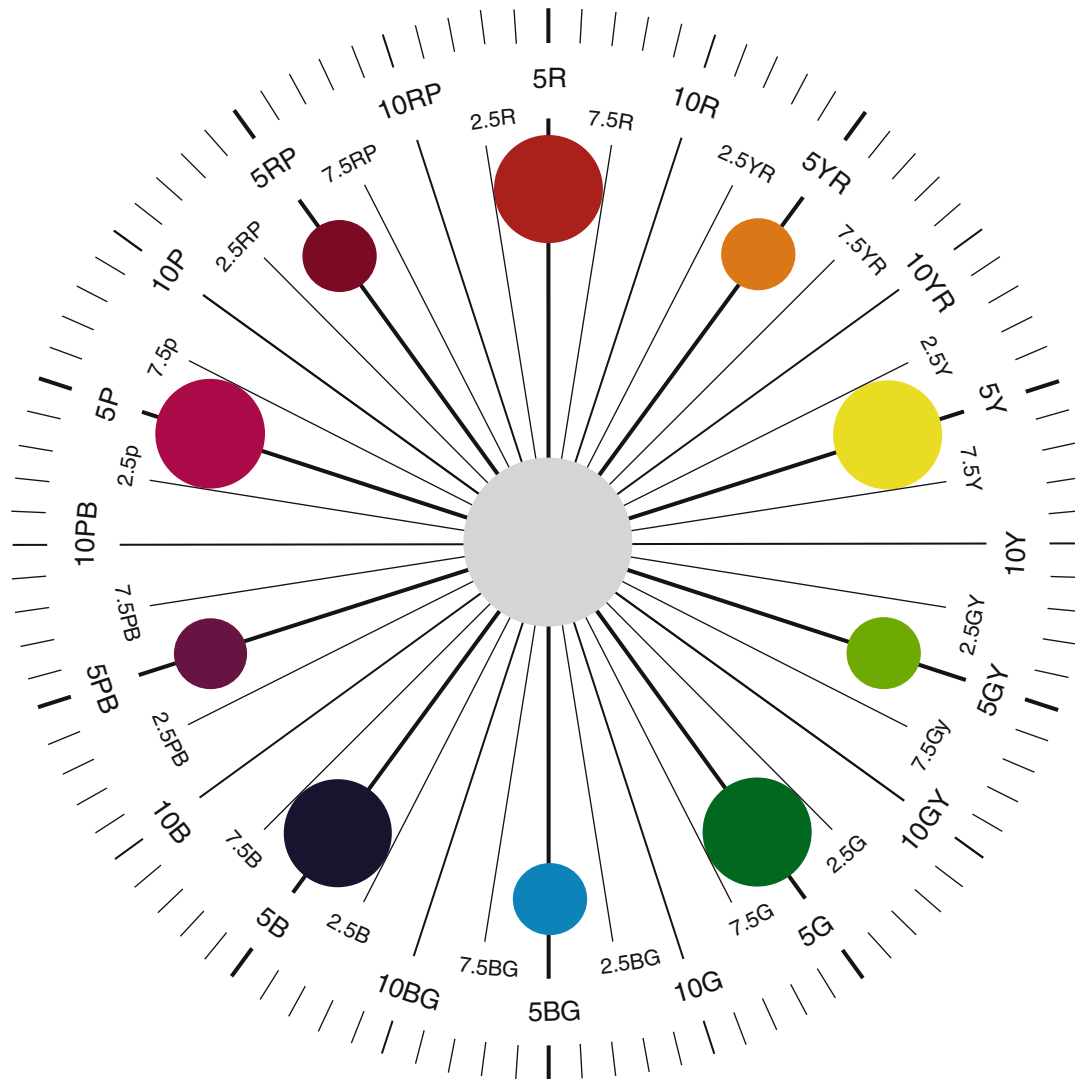


Fig. 1 Color circle of the Munsell color system

hue H , value V (lightness), and chroma C . These data are the three coordinates of the Munsell color solid, characterized by cylindrical coordinates and corresponding to the three characteristics of visual perception.

The ► [color circle](#) of the color solid, the hue scale, is divided into 100 perceptually equal parts according to 10 shades each of the following 5 reference and 5 mixed colors: red (R), yellow-red (YR), yellow (Y), green-yellow (GY), green (G), blue-green (BG), blue (B), purple-blue (PB), purple (P), and red-purple (RP) (Fig. 1).

The axis of the Munsell color solid accommodates gray (neutral, N) colors. The achromatic scale is divided in a perceptually equidistant manner from 0 to 10. The Munsell value (lightness) of a perfectly absorbing surface (ideal black) is 0, while that of a perfectly and diffusely reflecting surface (ideal white) is 10. The Munsell chroma increases with the distance from the achromatic axis (Fig. 2). In the Munsell system, colors are marked as $H\ V/C$, for example, 10RP 5/6. The shape of the Munsell color solid is shown in Fig. 3. The relationship between the Munsell color system and CIE has been tabulated.

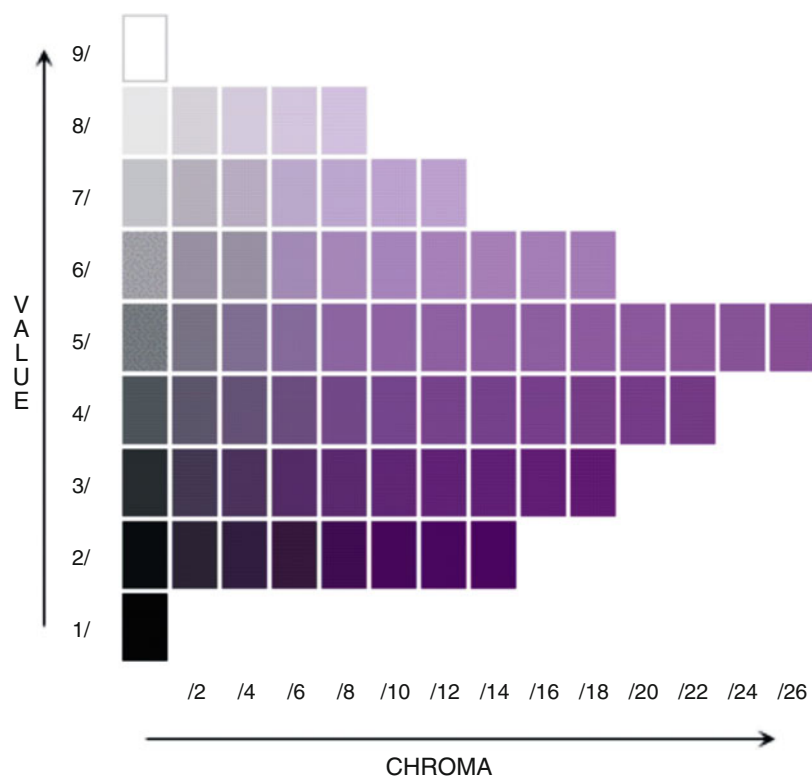


Fig. 2 Axial section of the Munsell color solid, with the Chroma and value scales

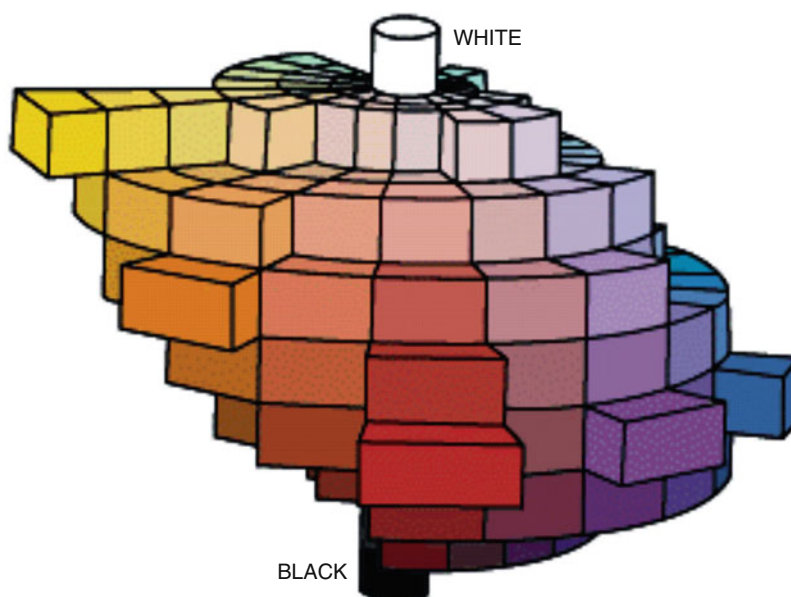


Fig. 3 Color solid of the Munsell color system

Natural Color System (NCS)

One of the latest ideas on color systematization relies on the Hering-Johansson theory, materialized as the color atlas by Hesselgren issued in 1953. Based on this atlas, in 1972 Hård, Sivik, and Tonnquist have developed the Natural Color System (NCS) adopted as a Swedish standard in 1979.

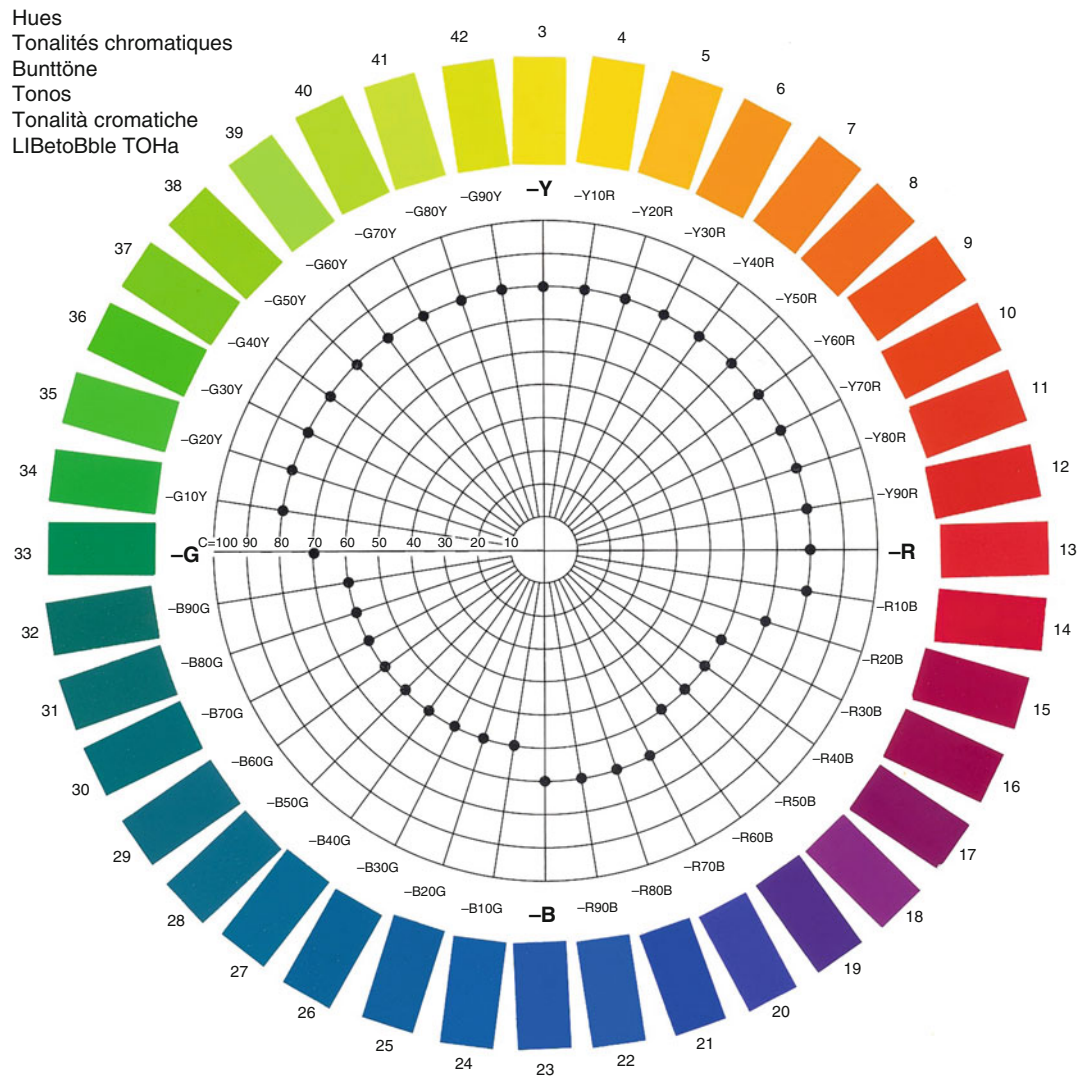


Fig. 4 Color circle of the NCS color system

The authors of this system started from Hering's idea about six elementary color perceptions, i.e., white (W), black (S), yellow (Y), red (R), blue (B), and green (G) – all the other color perceptions being more or less related to them. In the NCS, every color is described by the degree of its similarity to the six elementary colors [4].

A color cannot be similar to more than two hues. Yellow and blue exclude each other, and so do red and green. The sum of the color variables defines the NCS chromaticness (c) of the perceived color and their ratio its hue (Φ).

In the NCS color system, colors are marked as $sc\text{-}\Phi$, for instance, 2040-G40Y, where s is blackness, c is chromaticness (a magnitude associated with saturation), and Φ is the hue of the color. In the color notation, the s and c values – both of two digits – are written without space and separated from Φ by a hyphen. The hue of the color in the example above is intermediary between green (G) and yellow (Y) in a ratio of 40 to 60.

The geometric form that the NCS assumes is a regular symmetric double cone with white and black at the vertices, while the other four preferential hues are on the circle of full colors, at corners of a square touching this circle (Figs. 4, 5, and 6). This color solid is of the same shape as that of the Ostwald system

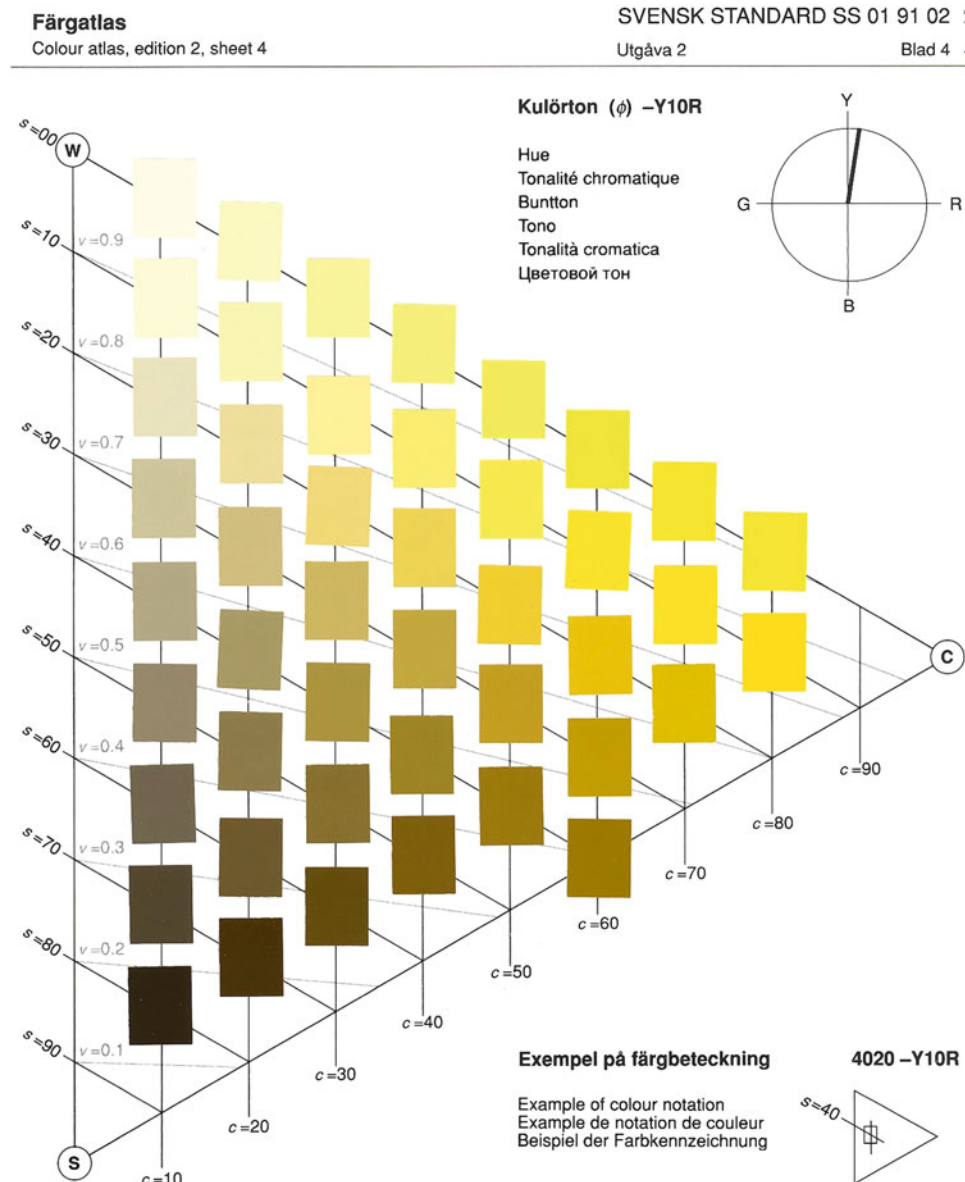


Fig. 5 Axial section of the NCS color solid

[2]. Also, the basic principle of some variables was adopted from the Ostwald system, but with a modified definition and scale. Similarities and differences between CIE and NCS color spaces have been tabulated, but no exact mathematical correlations were established.

The significance of this system is that it operates with a tetrachromatic color description as a possible way of visual color description.

Coloroid System

Coloroid is a color system of surface colors enlightened by daylight and sensed by normal color vision observers, built on harmonic color differences according to sensation, that well approximates the aesthetic uniformness. Coloroid is the only color system that has a direct transformation relation with the CIEXYZ system. It has been elaborated at the Budapest Polytechnical University by Nemcsics and was published

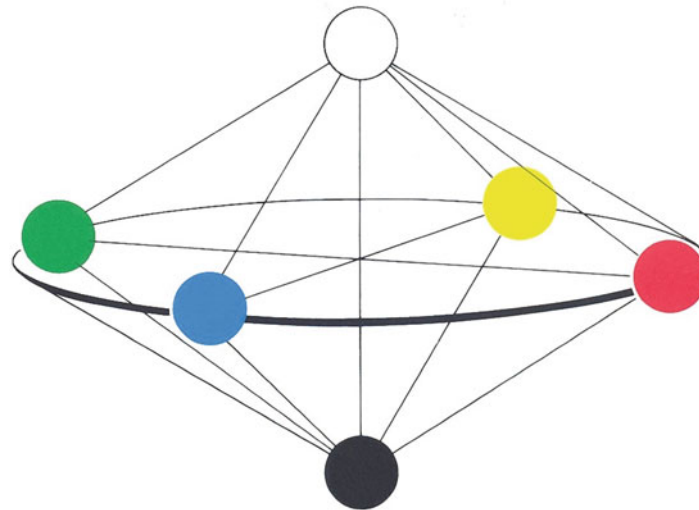


Fig. 6 Color solid of the NCS color system

in 1975 for the first time. From 1982 on, it has been a Hungarian technical directive, and from 2002 on, it is a Hungarian standard [5–7].

Coloroid coordinates are semipolar coordinates, representing the members of the population of colors placed inside a linear circular cylinder, to be used for the explicit definition of color points, namely, the angular coordinate representing numerically the hue of the color (A), the radial coordinate representing numerically the saturation of the color (T), and the vertical axial coordinate representing the luminosity of the color (V).

Absolute white (W) is placed on the upper limit point of the axis of the color space. It is the color of a surface illuminated by CIE D65 beam distribution, with perfectly scattered reflection, having both Coloroid luminosity value and Yw color component value of 100.

Absolute black (S) is placed on the lower limit point of the axis of the color space. It is the color of a surface illuminated by CIE D65 beam distribution, perfectly light absorbing ($\beta = 0$ luminance factor), having both Coloroid luminosity value and Ys color component value of 0.

The Coloroid limit colors are the most saturated colors that can be drawn onto the surface of the cylinder comprising the Coloroid space, located along a closed curve. In the CIE 1931 color diagram, colors are located along spectrum color lines between $\lambda = 450$ nm and $\lambda = 625$ nm; moreover, colors are located along the line connecting the points $\lambda = 450$ nm and $\lambda = 625$ nm.

The Coloroid basic colors are 48 different limit colors characterized with integer numbers, being located at approximately identical number of harmony intervals to each other. The Coloroid basic colors are recorded in the CIE 1931 diagram by the jangle. The jangle is the angle of the half line originated from the D65 point of the CIE 1931 color diagram to the x axis.

The Coloroid color planes are the half planes delimited by the achromatic axis of the color space, having the same hue and dominant wavelength. In each color plane, colors are enclosed by the neutral axis and two curves, the so-called Coloroid delimiting curves. The shape of surfaces enclosed by delimiting curves is different for each hue and depends on the luminosity of the spectrum color or of the purple being located on one apex of the color plane. Along the vertical lines of the nets drawn on the color planes, Coloroid saturation values are identical; along their horizontal lines, Coloroid luminosity values are identical. Colors implemented with various means or colors created in the nature, belonging to individual color planes, are enclosed by internal delimiting curves.

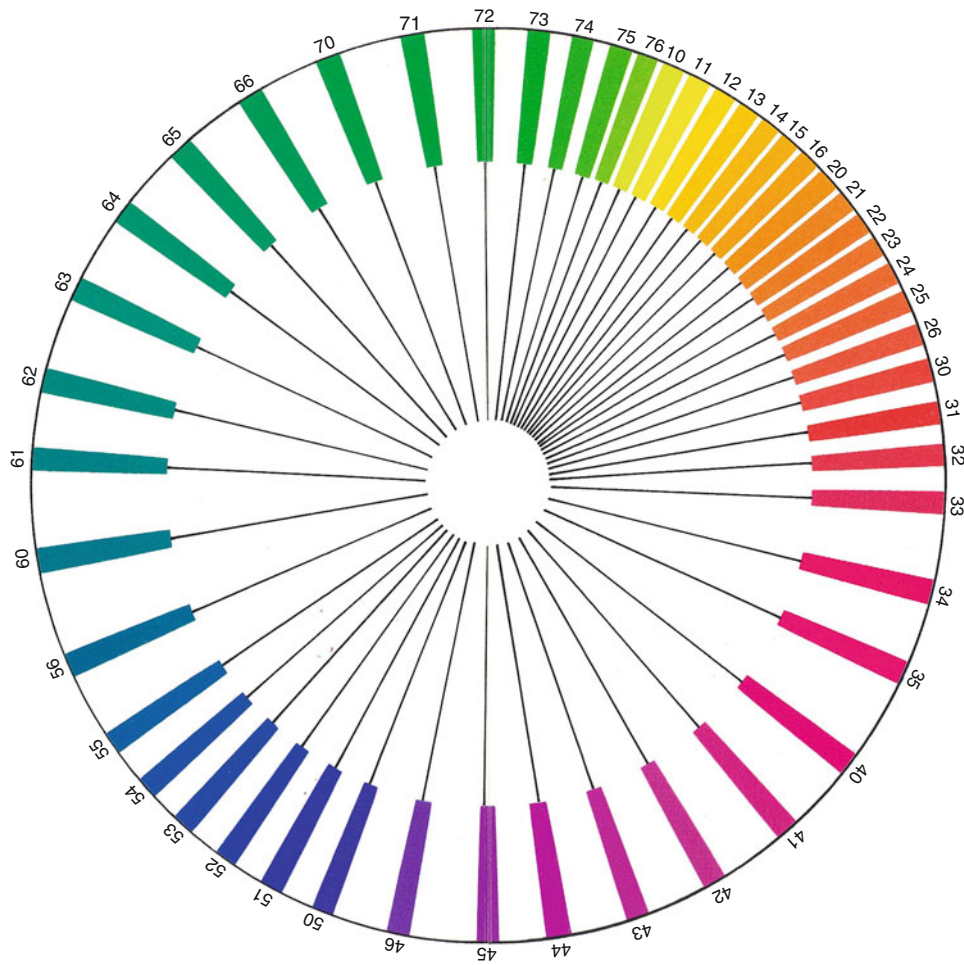


Fig. 7 Color circle of the Coloroid color system

The Coloroid basic hues are the hues belonging to Coloroid basic colors. Similarly to basic colors, there are 48 Coloroid basic hues. In color planes A10, A11, A12, A13, A14, A15, A16 yellow, in color planes A20, A21, A22, A23, A24, A25, A26 orange, in color planes A30, A31, A32, A33, A34, A35 red, in color planes A40, A41, A42, A43, A44, A45, A46 purple and violet, in color planes A50, A51, A52, A53, A54, A55, A56 blue, in color planes A60, A61, A62, A63, A64, A65, A66 cold green, in color planes A70, A71, A72, A73, A74, A75, A76 warm green hues exist.

Coloroid saturation is a characteristic feature of the surface color quantifying its saturation, i.e., its distance from the color of the same Coloroid achromatic luminosity measured on a scale that is aesthetically near to uniform. Its denotation is T. The saturation of the limit colors is equal to 100. The saturation of absolute white, absolute black, and gray is equal to 0. In the Coloroid space, colors of identical saturation are located equidistant to the achromatic axis, on a coaxial cylinder.

Coloroid lightness is a characteristic feature of the surface color denoting the distance measured from absolute black on an aesthetically near-uniformly graduated scale. Its denotation is V. The lightness of absolute black is equal to 0. The lightness of absolute white is 100. In the Coloroid space, colors of identical lightness are located in planes perpendicular to the achromatic axis. Numerical values of the Coloroid lightness of a surface color are determined by the expression $V = Y^{1/2}$.

Coloroid hue is a characteristic feature of the surface color denoting its hue on a scale distributed into 48 sections on an aesthetically near-uniformly graduated scale. Its denotation is A. The Coloroid hue of

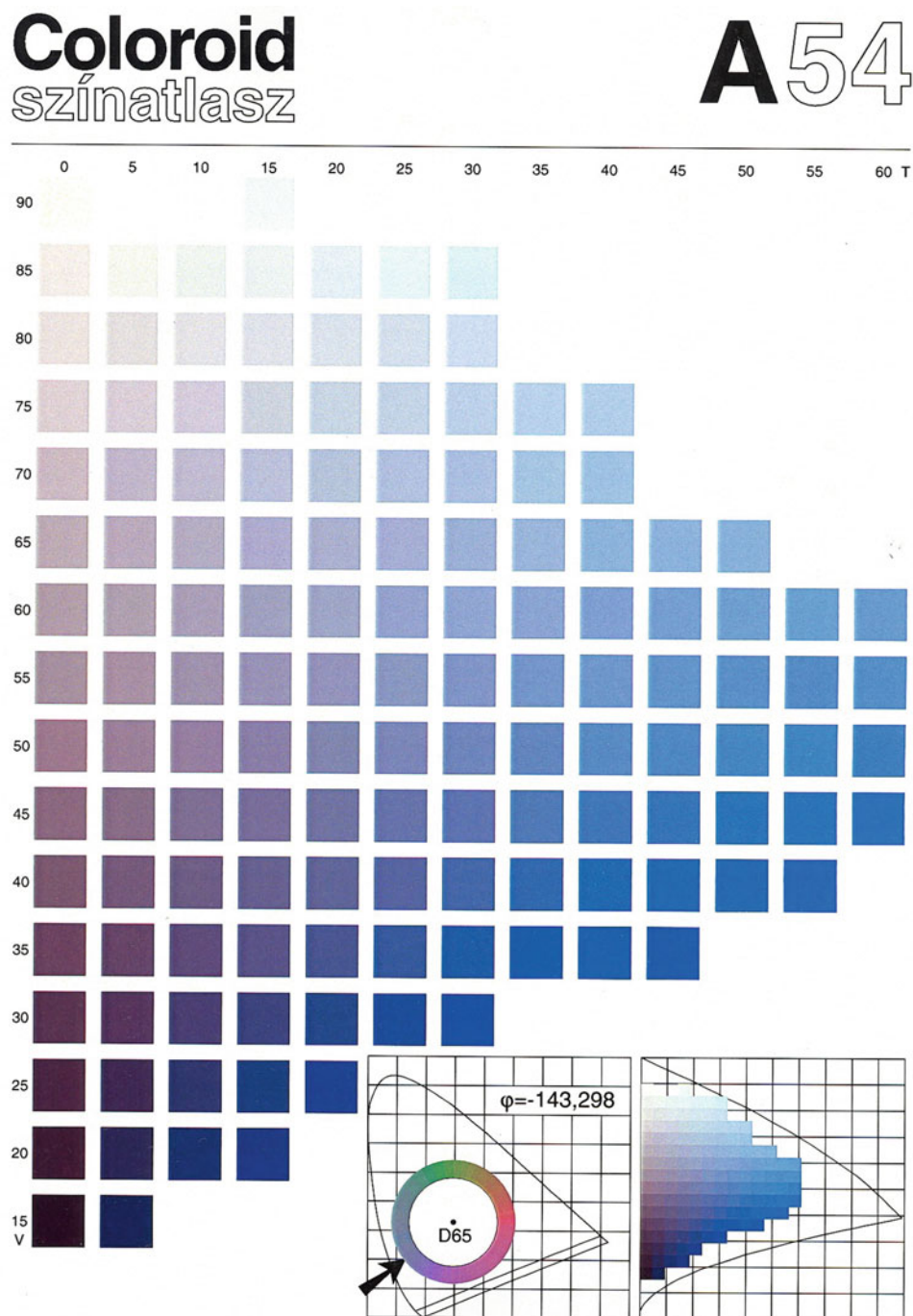


Fig. 8 Axial section of the Coloroid color solid

the surface color is a function of the dominant wavelength. In a Coloroid space, surface colors having identical hues lie in the Coloroid color planes.

The color notation in the Coloroid system is expressed by hue (A)–saturation (T)–lightness (V), for instance, 13-22-56 (Figs. 7, 8, and 9).

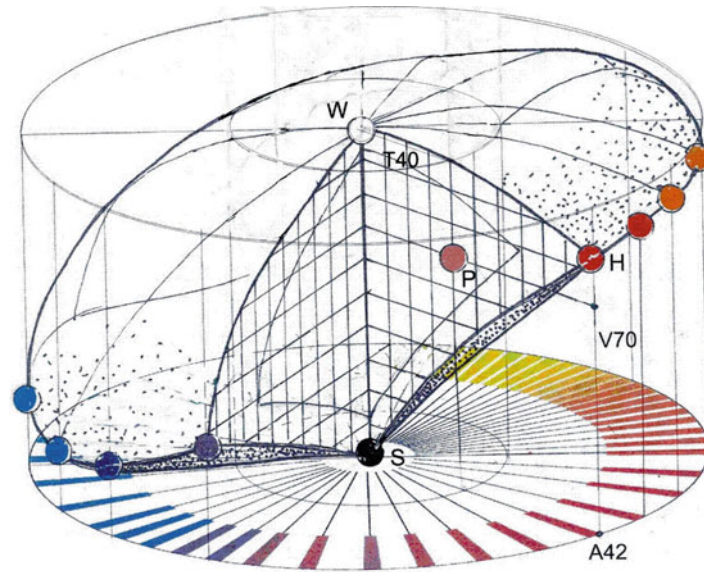


Fig. 9 Color solid of the Coloroid color system

Küppers' Atlas and Rhombohedral Color System

The German engineer Harald Küppers has published an atlas specifically useful for the graphic arts and the printing industry, containing more than 5,500 nuances [8]. The color samples of this atlas have been produced by the technique of four-color printing, mixing the four transparent dyes, yellow, magenta, cyan, and black, with the concurrence of the white background of the paper.

The gradations of the mixtures are expressed in percentages directly equivalent to the proportion of surface covered by each dye, so that this notation not only is useful to designate the different nuances but also as a formula to produce the colors. The variation is made by differences of 10 % between an individual sample and the next one and between a chart of colors and the next one.

The published color charts are divided into five series; three of them are said to be of achromatic mixture because of the intervention of black, and the other two are considered of chromatic mixture due to the exclusive intervention of yellow, magenta, and cyan. In the first three series, black is added to a mixture of two chromatic dyes – made in 10 % steps of variation, and held constant for the whole series – in 10 % steps of variation from one chart to another. In the fourth series, yellow is added in successive charts to a fixed mixture of two chromatic dyes (magenta and cyan). Series 1–4 have 11 charts, with 0 %, 10 %, 20 %, 30 %, 40 %, 50 %, 60 %, 70 %, 80 %, 90 %, and 99 % of the dye being added to the fixed binary mixture. The fifth series has two additional charts: one with yellow-cyan mixtures and 99 % of magenta and the other with yellow-magenta mixtures and 99 % of cyan.

Küppers also represents his system as a three-dimensional space, either as a cube (Fig. 10) or with a rhombohedral shape, constituted by an upper tetrahedron, a central octahedron, and a lower tetrahedron (Fig. 11). In the rhombohedral model, white is placed in the upper vertex of the upper tetrahedron, in whose base the three subtractive primaries are placed: yellow, magenta, and cyan. This base is also one of the faces of the central octahedron. The lower triangular face of the octahedron holds the three colors resulting from the mixture of the subtractive primaries in pairs: green (yellow with cyan), red (yellow with magenta), and blue (cyan with magenta). This face is, in turn, shared with the lower tetrahedron, in whose lower vertex black is placed.

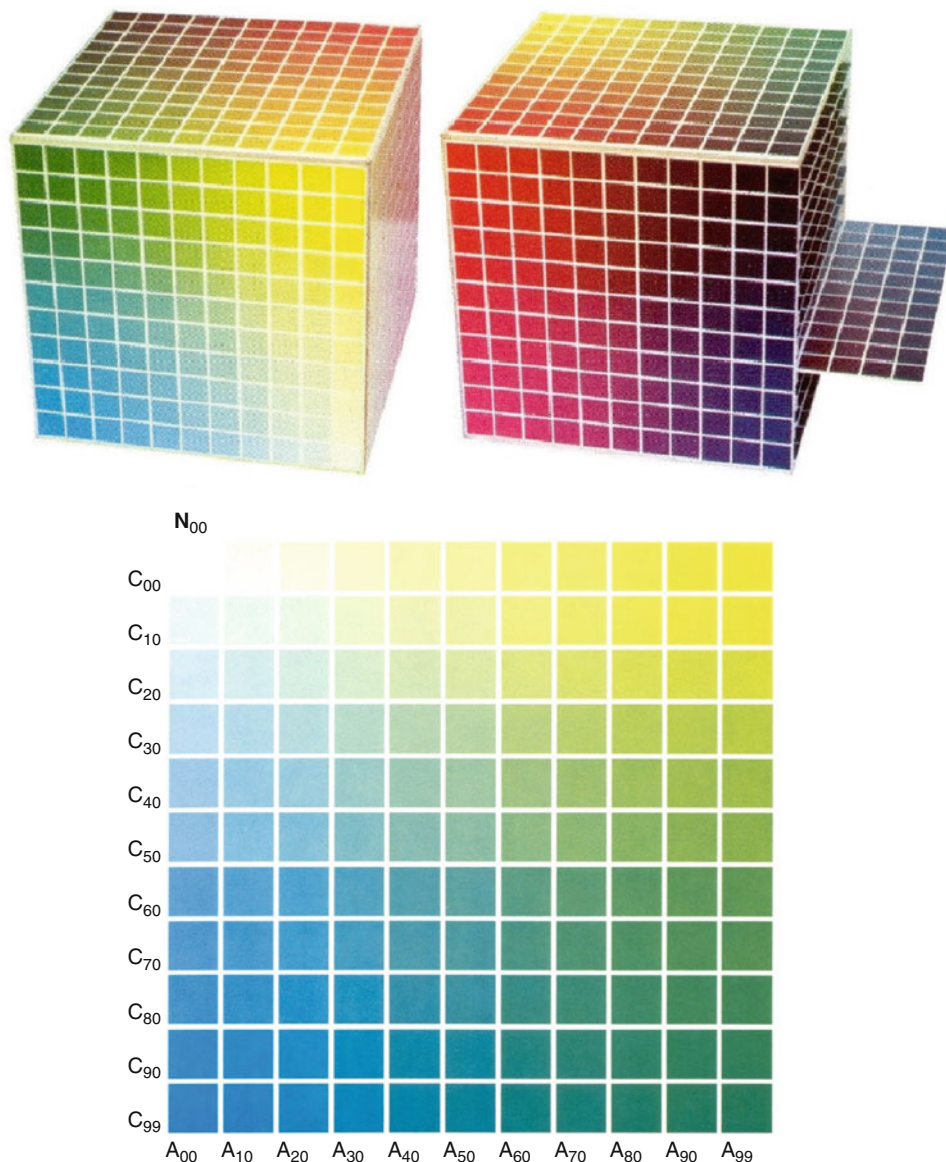


Fig. 10 Harald Küppers, the model of his atlas in a cubic shape, and a page from it

Additional Studies, Classifications, and Evaluations of Color Order Systems

The bibliography about historical, comparative, or classificatory analysis of color order systems is extensive. In addition to the already stated references, it is possible to mention articles by Spillmann [9], Robertson [10], Sivik [11], and Tonnquist [12]. The International Color Association devoted a whole congress to the theme of color order systems in 1983 [13] and had a study group on this subject from 1978 to 1990, chaired successively by Günter Wyszecki, Fred Billmeyer, James Bartleson, and Nick Hale (see [14]).

Specially interesting is the analysis made by Billmeyer [15], who deals with the history and the principles of various systems, establishes comparisons and differences, and offers data about the attempts of conversion among the notations of various systems. William Hale [16] discusses the uses of color order systems, including those that have a relevant theoretical or scientific basis as well as those more pragmatic and with a specific commercial purpose. Tonnquist [17] offers another criterion to classify color order



Fig. 11 Küppers' rhombohedric model

systems. He divides them into (a) *physical*, those that have actual samples as reference and that only exist in terms of an atlas or a color chart; (b) *psychophysical*, those whose definition is given by means of valences for a set of points in a color space, and whose definition is only valid to a combination of observer, illuminant, and measuring instrument, as, for instance, the CIE system; and (c) *perceptual*, those defined in terms of elementary color percepts, mental references of certain basic colors which serve to describe all the remaining colors, as, for instance, the NCS system.

Some countries have adopted certain color systems as national standards. However, no color system is favored with the acceptance as an international standard. During the 6th Congress of the International Color Association, a specific discussion about the question if any particular system is better than the others took place ([18], vol. I, pp. 163–172). The conclusion was that there is no particular system that is *the* best for all the applications, which may cover fields so different as color education, artistic practice in various disciplines, professional practice in diverse branches of design (architectural, graphic, industrial, textile, landscape design), specification of color in materials so dissimilar as paper, clothes, leather, plastics, metals or in complex industries such as the automotive, the food industry, color reproduction in TV, video and computer displays; some systems are more useful than others for certain specific problems. In the 7th Congress of the AIC, a round table on color order systems was also organized ([19], vol. A, pp. 173–174) in which there was a consensus on some points, among them (a) that physical color samples, although they are useful, are not essential to a color system and (b) that broadly, the systems can be divided into two types: systems of color appearance (a typical example would be the NCS) and systems of color stimuli (an example would be the CIE system).

The interested reader can look for additional information on description, analysis, and comparison of color order systems in Caivano [20], Stromer and Baumann [21], Silvestrini, Fischer and Stromer [22], Stromer [23], Kuehni [24], and Spillmann [25], among other sources. There is also an excellent website devoted to this subject: www.colorsystem.com.

Cross-References

- [Chevreul, Michel-Eugène](#)
- [CIE 1931 and 1964 standard colorimetric observers; history, data and recent assessment](#)
- [Color Circle](#)
- [Color Contrast](#)
- [Color Harmony](#)
- [Complementary Colors](#)
- [Itten, Johannes](#)
- [Munsell, Albert](#)
- [Ostwald, Wilhelm](#)
- [Otto, Runge, Phillip](#)
- [Philosophy of Color](#)
- [Primary Colors](#)
- [Richter, Manfred](#)
- [Unique Hues](#)

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