Co-funded by the
Erasmus+ Programme
of the European Union

ICT-TEX

Training module: FINISHING, PRINTNIG and FUNCTIONALIZATION

Course: Basic Principles of Textile Printing

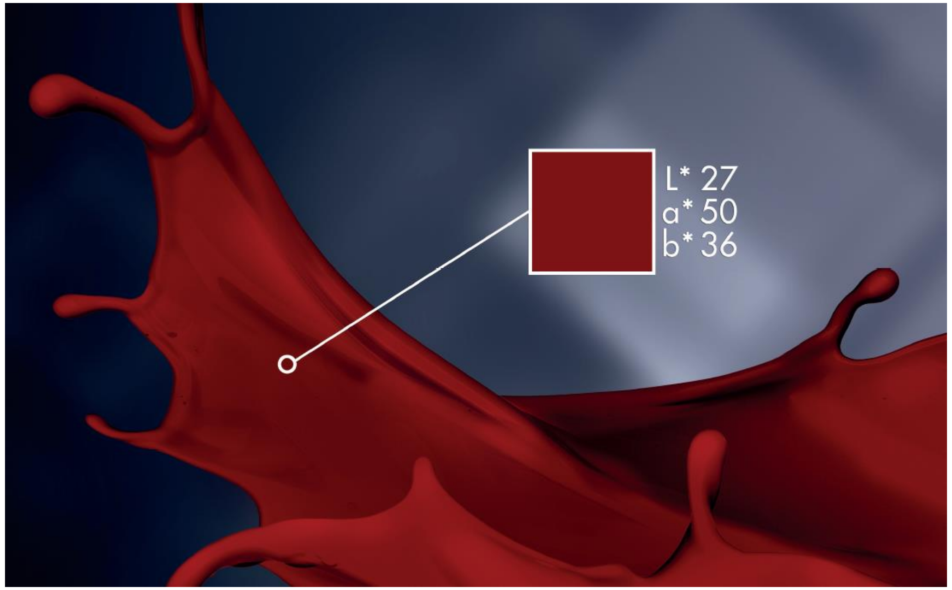
The course is developed under Erasmus+ Program Key Action 2:
Cooperation for innovation and the exchange of good practices Knowledge Alliance

ICT IN TEXTILE AND CLOTHING HIGHER EDUCATION AND BUSINESS

Project Nr. 612248-EPP-1-2019-1-BG-EPPKA2-KA

Co-funded by the Erasmus+ Programme of the European Union

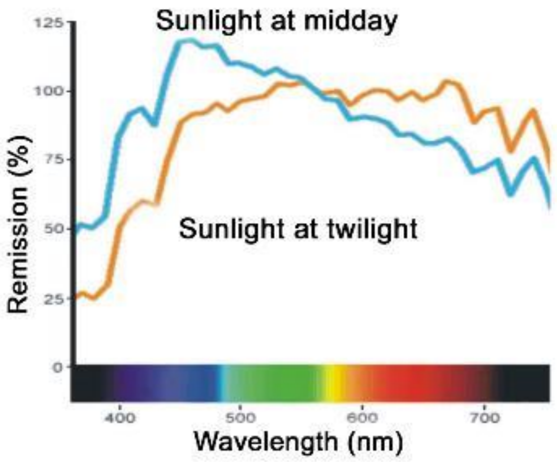
❑ INTRODUCTION

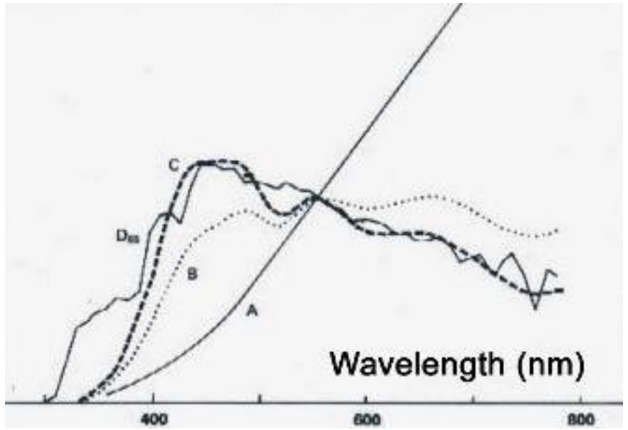


- ❑ Color metrics imply objective color measurement, based on the simulation of the visual experience of color, but in a much more precise system, which is performed by a spectrophotometer device. Color metrics involve objective, numerical evaluation of color, accurate color reproduction, and precise color differences.
- ❑ In colour metric, by colour measurement, each colour sensitive element associates the parameters required for its unambiguous (numeric) characterization. This implies accurate and precise evaluation of colour, its accurate reproduction and accurate specification of colour differences.

❑ DEVELOPMENT AND LIGHT SOURCES

- ❑ The development of the system for the numerical evaluation of colours and the differences between them and their application in the industry begins in the 30s of the 20th century as a result of the development of science and technology and the growing demands on quality and reproducibility. At the 6th International congress of International commission for the light sources standardization (Commission Internationele de l'Eclairage - CIE), Geneva 1924, the first section of colorimetry was established. At the 8th CIE Congress in 1931, also in Geneva, the first, basic model for the quantitative determination of colors and the differences between them was presented and accepted.
- ❑ Given the fact that light is the most important precondition for visualization of the surrounding world, meaning colors and objects, it is necessary to use standardized light sources for reproducible definition and comparison of colors. The most important source of light in man's life is certainly the sun and therefore it was necessary to produce and standardize the source of spectral energy distribution closest to the sunlight daylight.





Standard light sources spectrums

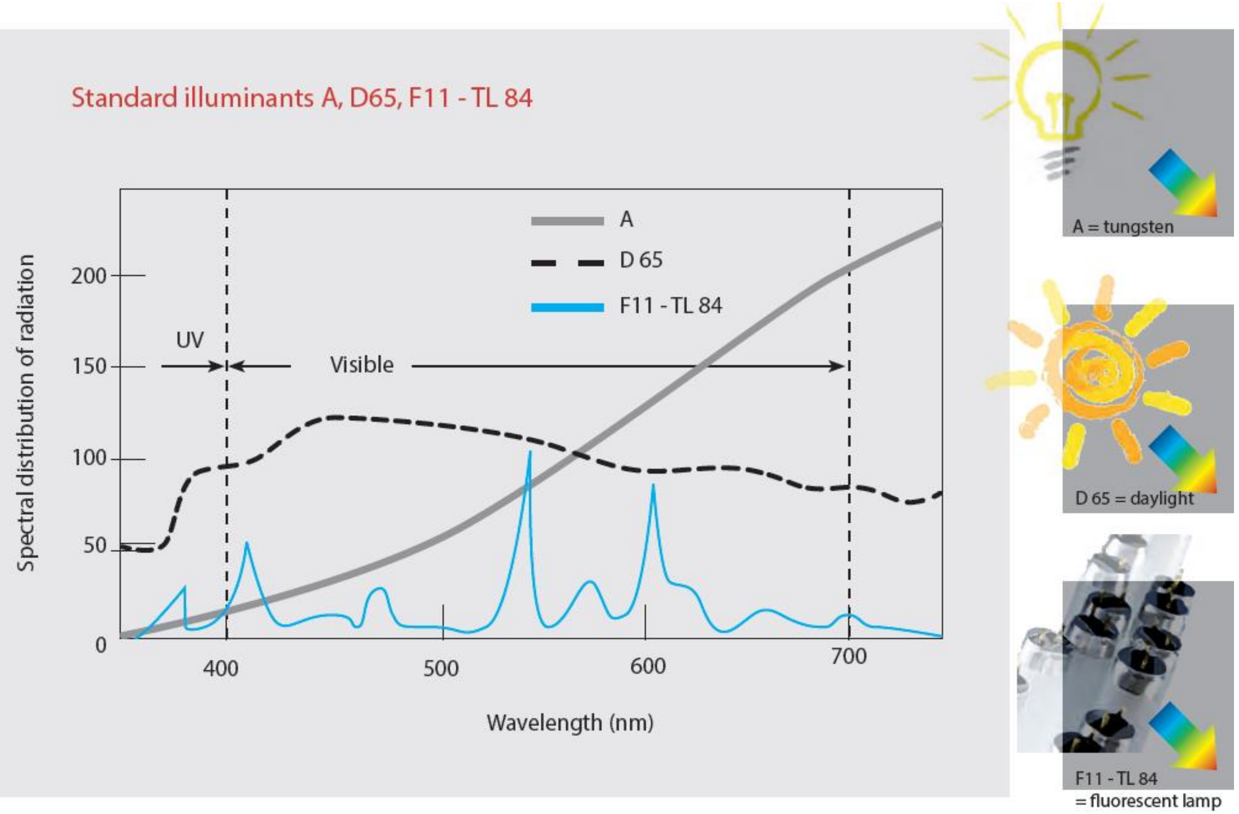
❑ LIGHT SOURCES AND STANDARD OBSERVER

Today, standard light sources are used for the objective evaluation of colors:

A – light of tungsten lamp, colour temperature 2856 K,

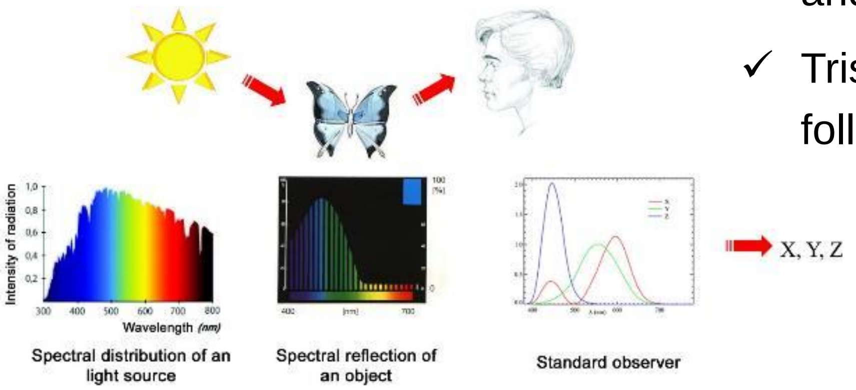
D_{65} – average daylight of colour temperature 6500 K

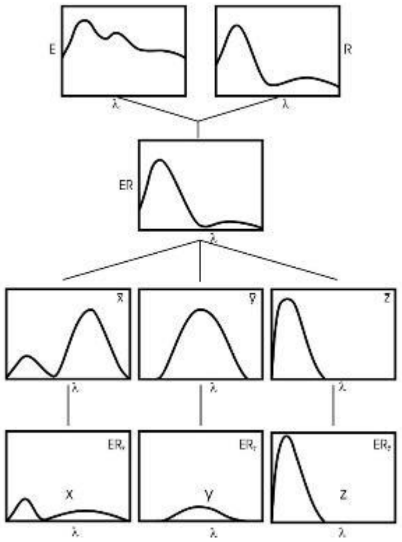
F2, F7 and F11 - fluorescent meaning cold white light.



- ❑ Since different humans perceive colour and appearance in different ways, subjectively, for the purposes of establishing a precise mathematical system for objective colour and colour differences evaluation, attempts have been made to „standardize“ the human observer as a numerical representation of what the „average person „ sees. This standard observer could than be used instead of a human observer when assessments are made instrumentally.

COLOUR METRICS





- ✓ From ***X, Y, Z*** values, using various mathematical equations, a colour parameters and colour differences can be calculated.
- ✓ Tristimulus (standard) colour values (X), (Y) and (Z) are defined based on the following mathematical equations:

$$X = \sum_{360}^{740} E_\lambda \bar{x}_\lambda R_\lambda \longrightarrow \text{Red - R}$$

$$Y = \sum_{360}^{740} E_\lambda \bar{y}_\lambda R_\lambda \longrightarrow \text{Green - G}$$

$$Z = \sum_{360}^{740} E_\lambda \bar{z}_\lambda R_\lambda \longrightarrow \text{Blue - B}$$

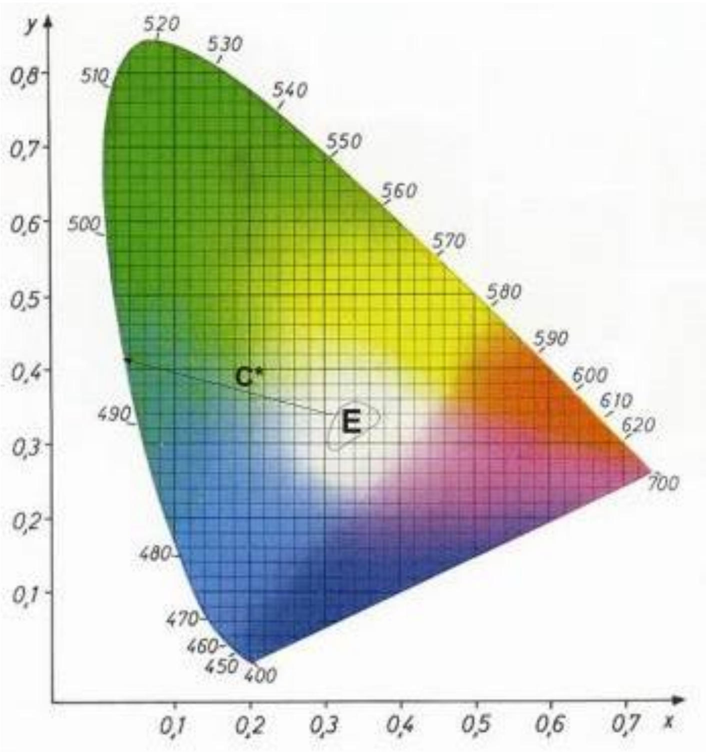
- ✓ CIE tristimulus values X, Y, Z numerically uniquely define colour, but they do not give any precise information about the appearance of the colour. Only value Y gives certain information about colour lightness.

For example, if two coloured samples has following tristimulus values:

X1 = 48,36	***Y1 =60,14***	*Z1 =11,50*
X2 = 53,36	***Y2 =66,14***	*Z2 =12,50*

It can only be concluded that the second sample is lighter (bigger **Y** value).

❑ COLOUR CHROMATICITY COORDINATES



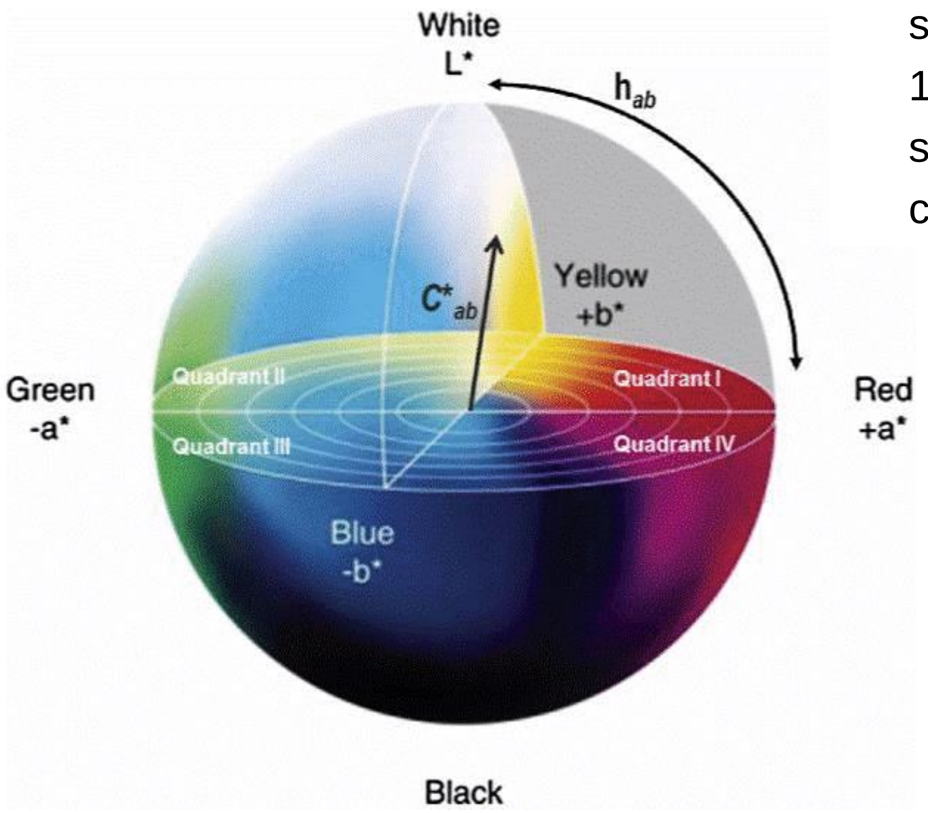
- The CIE tristimulus values of X, Y and Z uniquely numerically define colour, but do not give any information about the descriptive color attributes. For a clearer definition of the color dimension, the CIE defines numerical color evaluation with color coordinates - ***chromaticity coordinates x*** and ***y*** - that provide information on ***H*** (Hue), and ***C*** (Chroma). „**x**", "**y**" values for each wavelength are obtained by computation according to formulas:

$$x = \frac{X_\lambda}{X_\lambda + Y_\lambda + Z_\lambda} \qquad y = \frac{Y_\lambda}{X_\lambda + Y_\lambda + Z_\lambda}$$

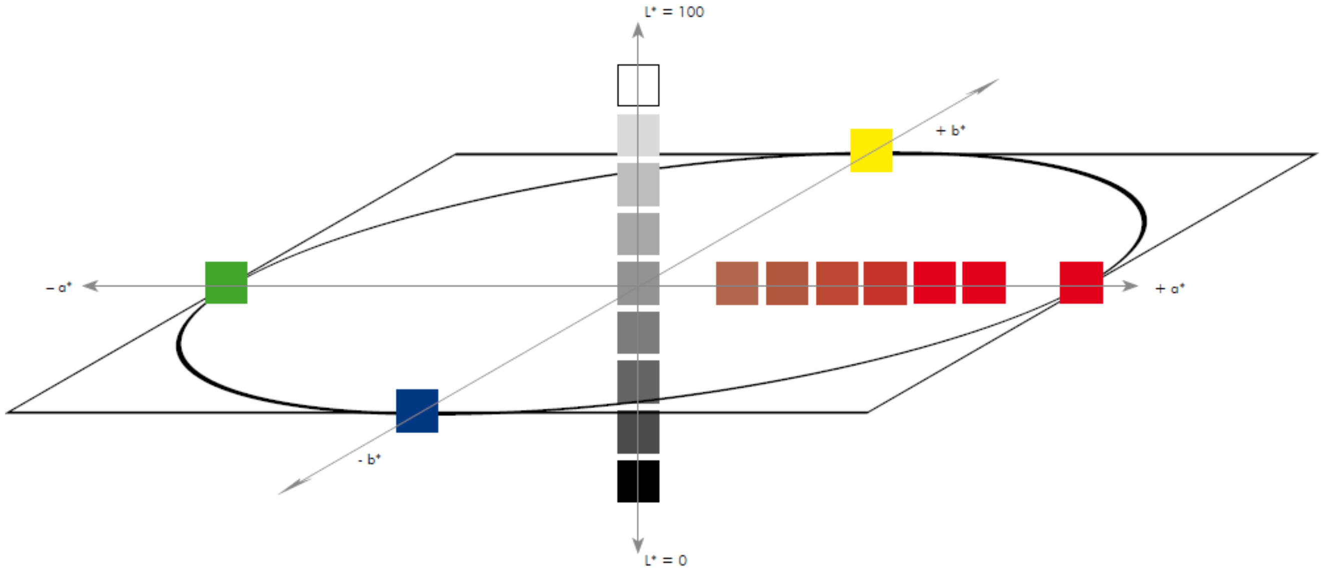
- Chromaticity coordinates defines a two-dimensional color space obtained by connecting endpoints of ***x*** and ***y***. The diagram is called a ***chromaticity diagram***, and because of its specific shape it is popularly called the ***horseshoe*** of colour.

- The position of the individual points in the ***chromaticity diagram***, given the values ***x*** and ***y***, gives accurate information on the ***hue*** and ***chroma*** of the given colour. The colour space of the horseshoe contains the hues of the entire visible spectrum.

❑ CIE SYSTEM



- The most complete and accepted system for evaluating and spatially displaying color is certainly the system of contrasting colors, proposed and standardized by the CIE (***Commission Internationale de l'Eclairage***) in 1976, under the name ***CIELAB***. The color space is defined by an equal spacing of the brightness value, ***L**** axis, with the corresponding color coordinates ***a****, ***b****, and corresponds to the visual color perception.



Co-funded by the Erasmus+ Programme of the European Union

ICT-TEX

- In CIELAB colour space, each colour is defined by *L*a*b** or *L*C*h** coordinates:
  - ***a**** - red – green axis
  - ***b**** - yellow – blue axis
  - ***L**** - lightness
  - ***C**** - chroma/saturation
  - ***h**** - hue

$$L^* = 116\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - 16$$

$$a^* = 500\left[\left(\frac{X}{X_n}\right)^{\frac{1}{3}} - \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}}\right]$$

$$b^* = 200\left[\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - \left(\frac{Z}{Z_n}\right)^{\frac{1}{3}}\right]$$

$$C^* = \left(a^{*2} + b^{*2}\right)^{\frac{1}{2}}$$

$$h = \arctan\left(\frac{b^*}{a^*}\right)$$

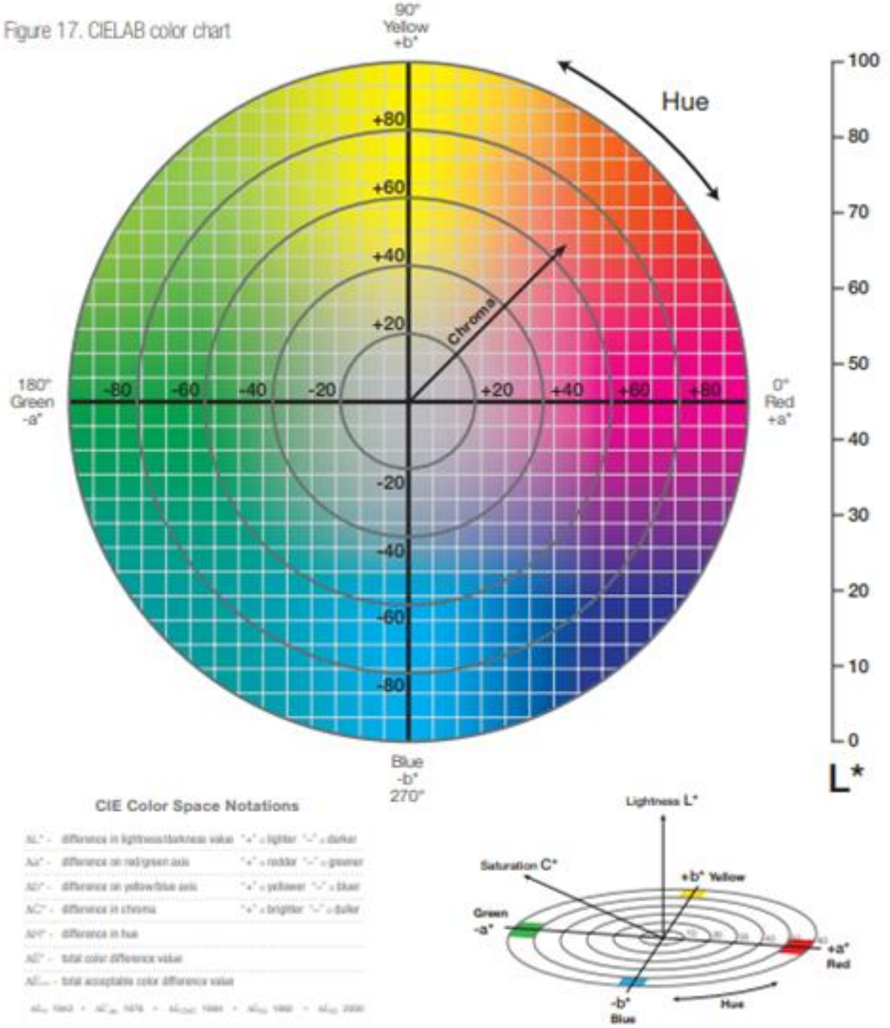
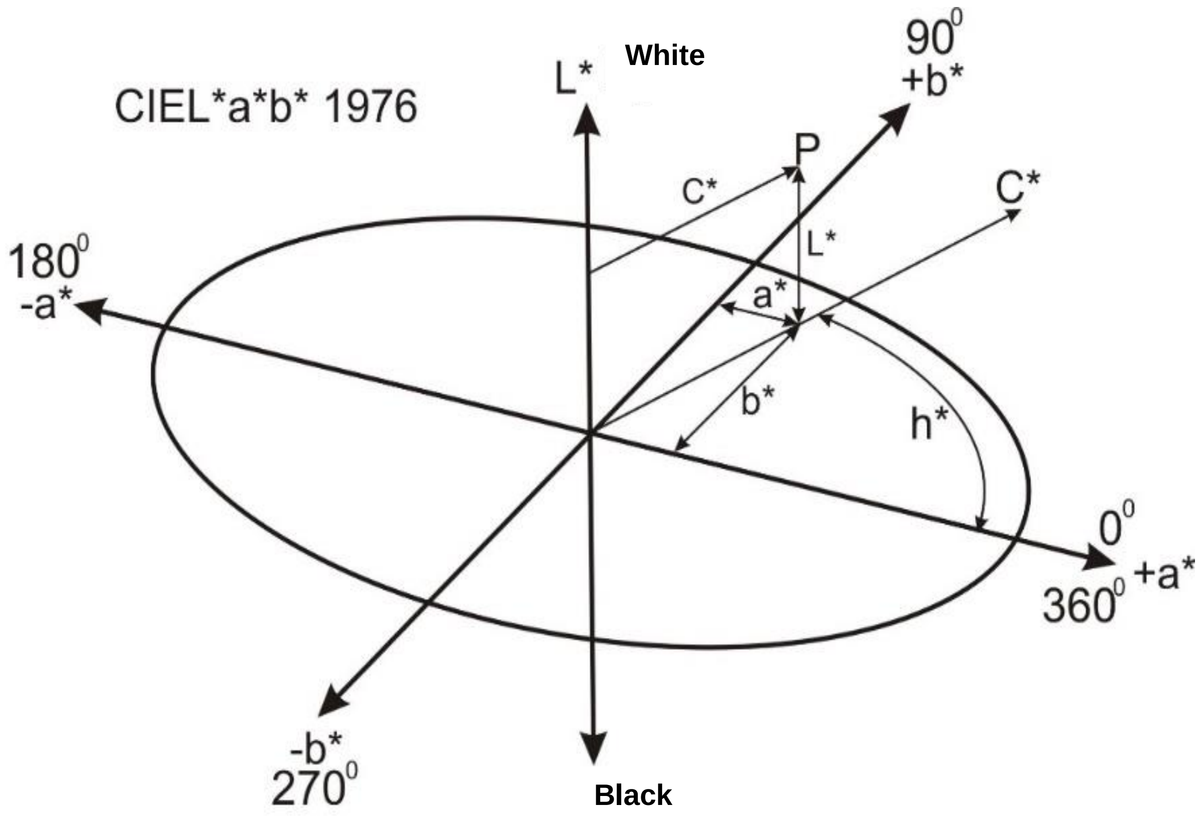
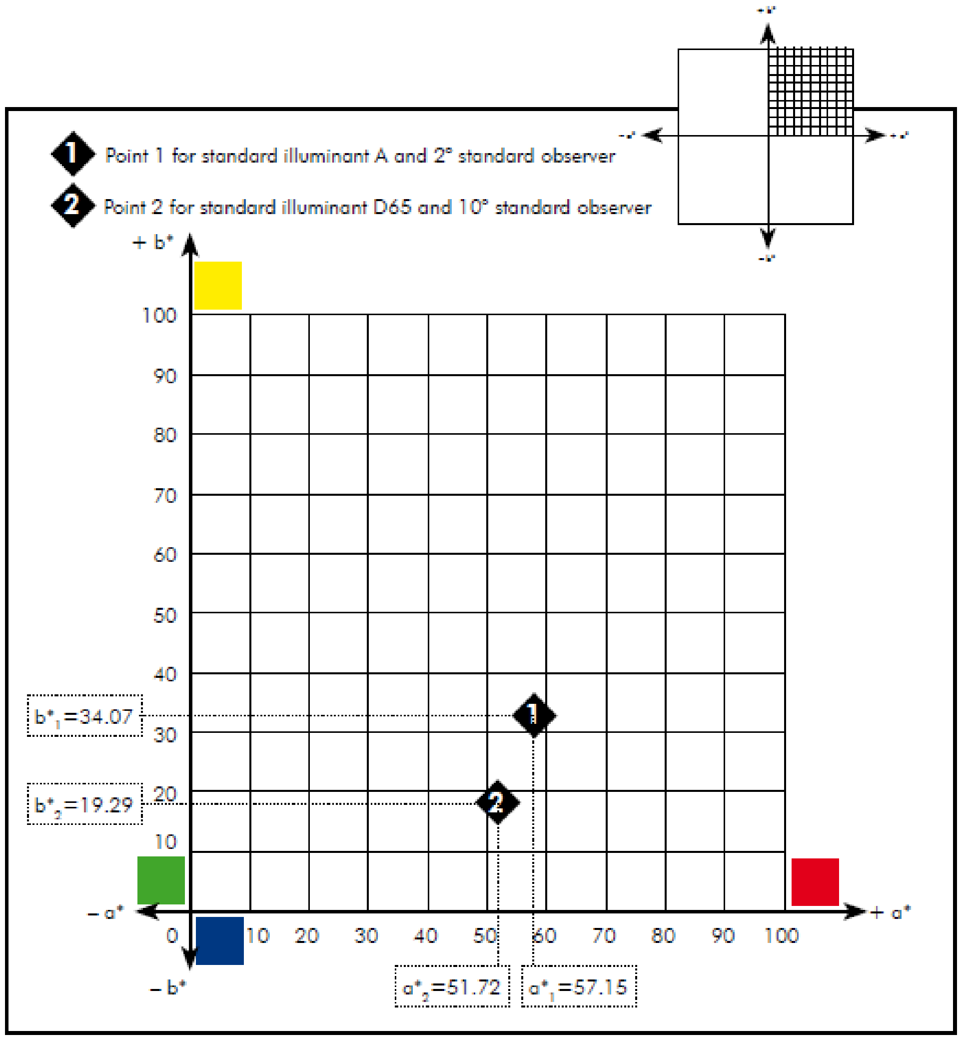
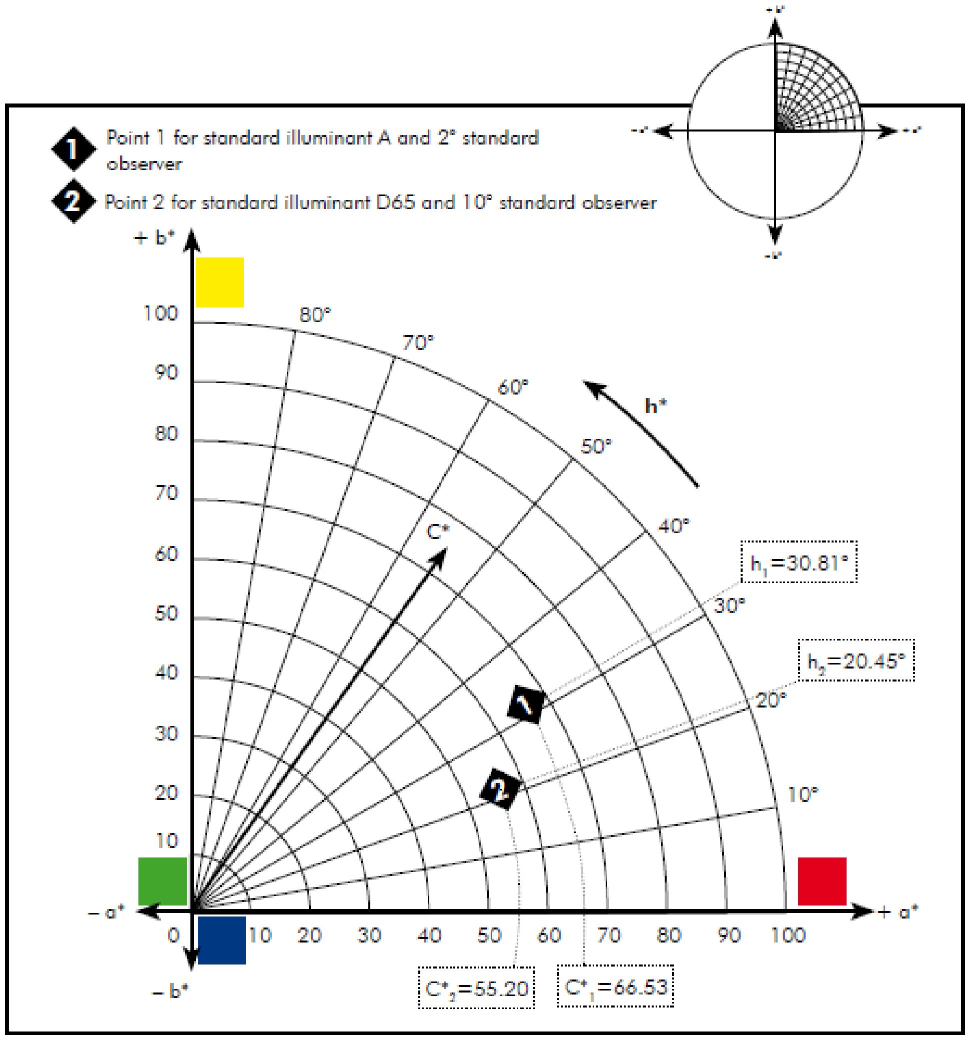


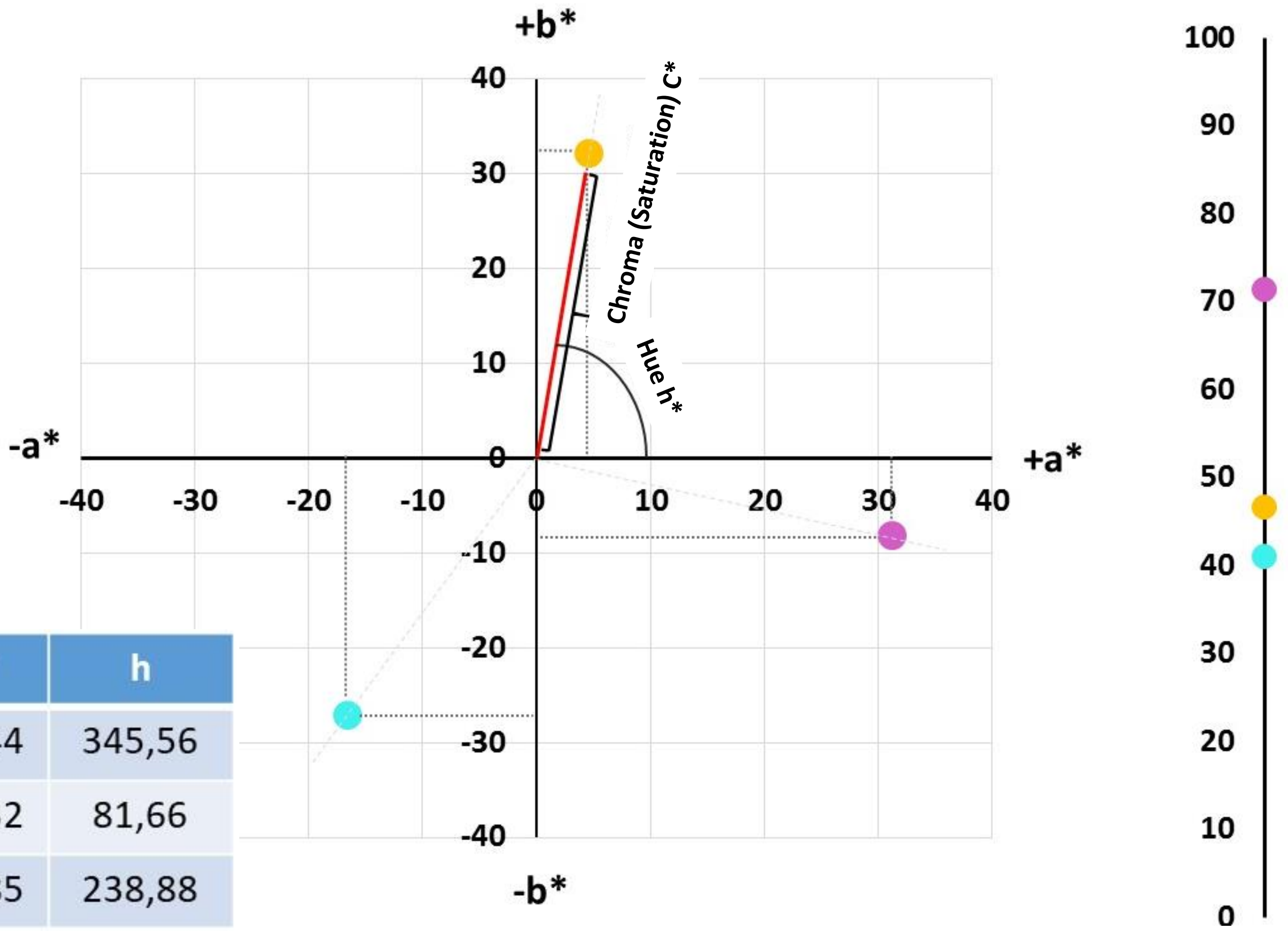
Figure 17. CIELAB color chart



- In CIELAB system ***hue*** is defined as the angle in ***a*/b**** diagram, it is evaluated in degrees, in counterclockwise direction, starting from coordinate +***a**** with ***h=0°*** (red).
- Chroma (saturation) ***C*** is defined as distance from central point (achromatic point) and is calculated from ***a**** and ***b**** by Pythagorean formula.


Point 1 for standard illuminant A and 2° standard observer
Point 2 for standard illuminant D65 and 10° standard observer
+ b*
– b*
– a*
+ a*
b*1=34.07
b*2=19.29
a*2=51.72
a*1=57.15
0
10
20
30
40
50
60
70
80
90
100


Point 1 for standard illuminant A and 2° standard observer
Point 2 for standard illuminant D65 and 10° standard observer
+ b*
– b*
– a*
+ a*
h*
C*
h1=30.81°
h2=20.45°
C*2=55.20
C*1=66.53
80°
70°
60°
50°
40°
30°
20°
10°

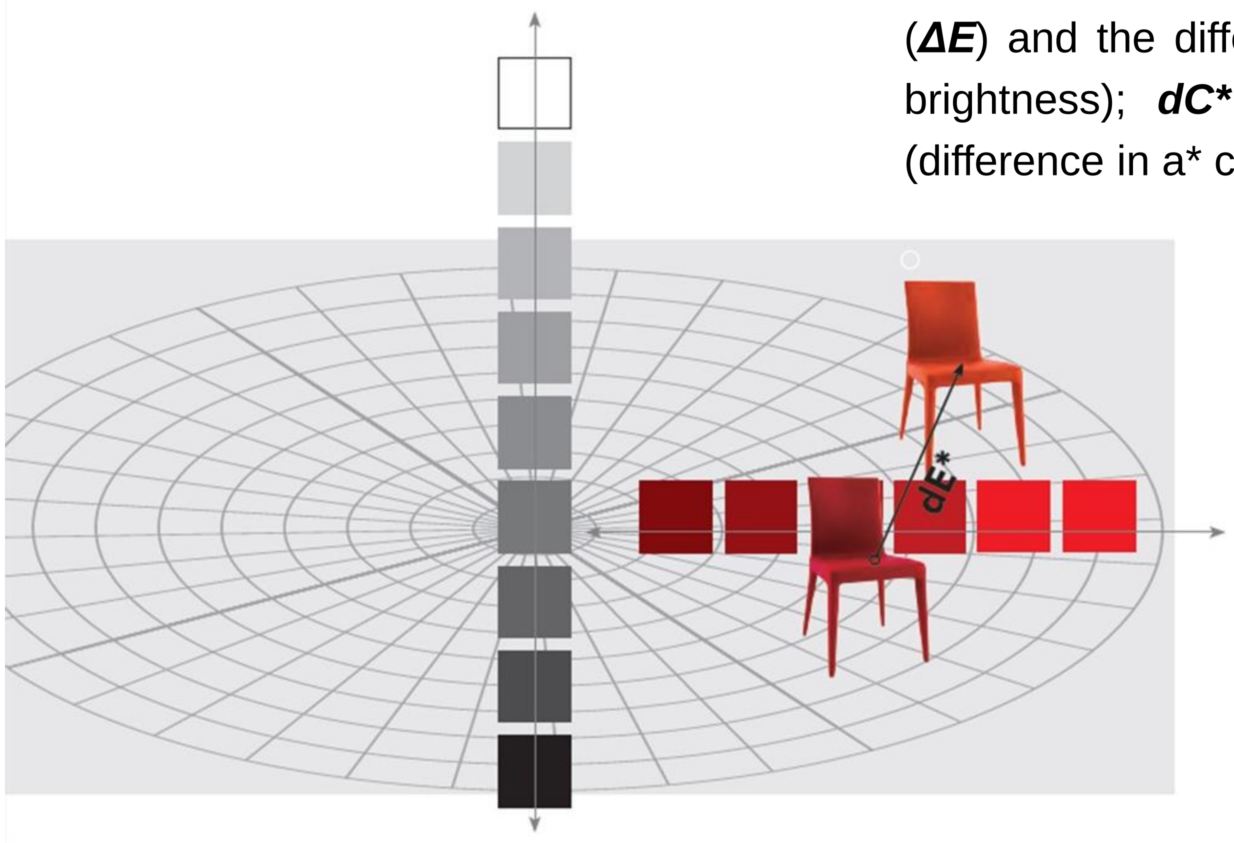


The example of positioning in CIELAB diagram

	L*	a*	b*	C*	h
Magenta	71,41	31,28	-8,27	31,44	345,56
Yellow	46,56	4,69	31,97	32,32	81,66
Cyan	41,04	-16,46	-27,27	31,85	238,88

❑ COLOUR DIFFERENCES

- The color difference of the two samples is evaluated based on the differences between the individual parameters of their colors. The color difference is determined numerically by calculating the value of the total color difference ***dE*** (***ΔE***) and the difference in the individual color parameters ***dL**** (difference in brightness); ***dC**** (difference in chromium); ***dh*** (difference in tone); ***da**** (difference in a* coordinates); ***db**** (difference in b* coordinates).



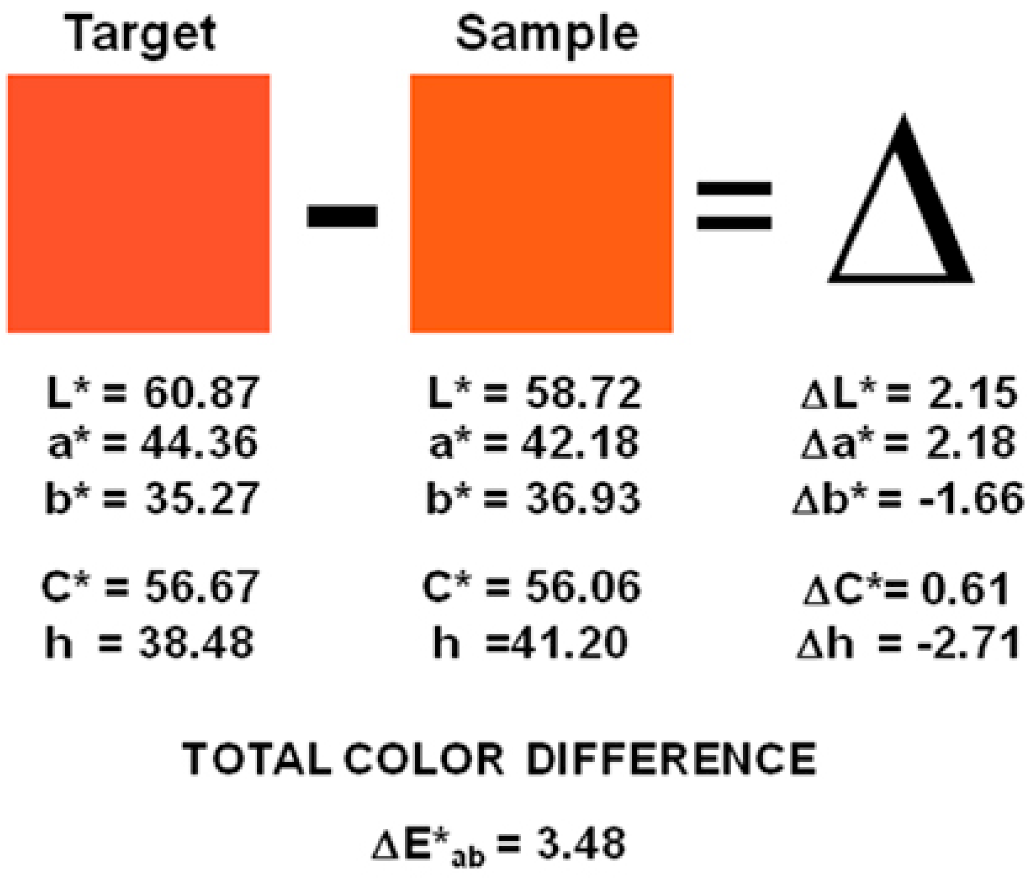
$$\Delta a^* = a^*_{sample} - a^*_{refernece_{sample}}$$

$$\Delta b^* = b^*_{sample} - b^*_{reference_{sample}}$$

$$\Delta L^* = L^*_{sample} - L^*_{reference_{sample}}$$

$$\Delta C^* = C^*_{sample} - C^*_{reference_{sample}}$$

$$\Delta H^* = 2 \cdot \sin\left(\frac{\Delta h^*}{2}\right) \cdot \sqrt{C^*_{sample} \cdot C^*_{reference_{sample}}}$$

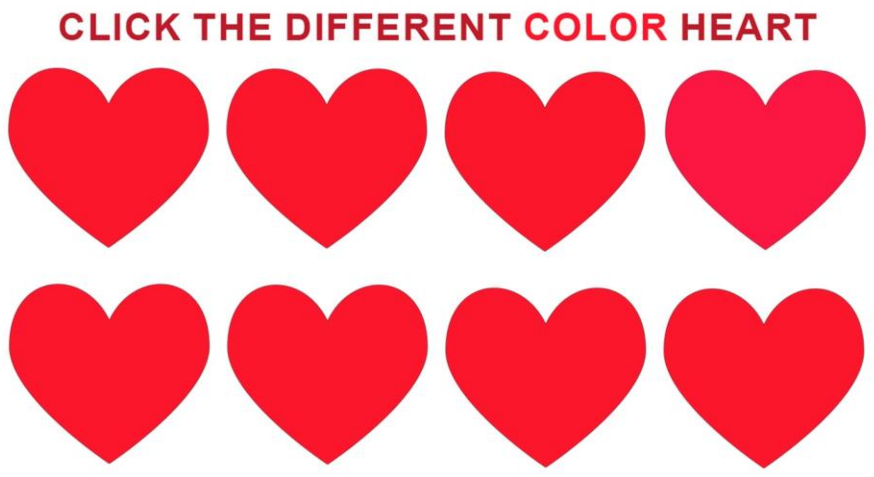


$$\Delta E = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \right]^{\frac{1}{2}}$$

$$\Delta E = \left[(\Delta L^*)^2 + (\Delta C^*)^2 + (\Delta H^*)^2 \right]^{\frac{1}{2}}$$

- ΔE value does not provide complete information on nature and magnitude of color differences. In CIEL*a*b* the color space of the color difference is described more precisely by calculating the differences between the individual parameters ΔL^*, Δa^*, Δb^*; ΔC^*, Δh.

- The ***CIELAB*** model results are not entirely in line with the visual perception of color differences, and the accelerated technological advancement imposes ever increasing demands on system development to allow accurate and realistic determination of color parameter values and their mutual differences in accordance with the visual perception of the same values.



Interpretation of differences :

+Δa* - more red, less green

- Δa* - more green, less red

+Δb* - more yellow, less blue

- Δb* - more blue, less yellow

+ΔL* - sample lighter than standard

- ΔL* - sample darker than standard

- In 1984, ***CMC (l:c)*** mathematical expression was introduced, including two additional factors for quantifying the tolerance of the differences in lightness (***l***) and chroma/saturation (***c***) taking into account the difference in hue for given values. The tolerance factor of the difference in lightness, ***l***, is determined with the value "2" so that the ratio of tolerance factor l:c = 2:1, since the eye is more sensitive to chroma than to the lightness. This ensures twice as much tolerance in lightness differences as in chroma differences - ellipsoid space color differences.

$$\Delta E=\left[\left(\frac{\Delta L^*}{lS_L}\right)^2+\left(\frac{\Delta C^*}{cS_C}\right)^2+\left(\frac{\Delta H^*}{S_H}\right)^2\right]^{\frac{1}{2}}$$

$$S_C=\frac{0{,}0638\cdot C_1^*}{1+0{,}0131\cdot C_1^*}+0{,}638$$

$$S_L=\frac{0{,}04975\cdot L_1^*}{1+0{,}017565\cdot L_1^*}$$

except if $L_1^* < 16$, than the $S_L = 0{,}511$

$$S_H=S_C(Tf+1-f)$$

$$f=\left[\frac{(C_1^*)^4}{(C_1^*)^4+1900}\right]^{\frac{1}{2}}$$

$T = 0{,}36 + |\,0{,}4\cos(h_1 + 35°)|$

Except when the h_1 is 164° and 345°, than the $T = 0{,}56 + |\,0{,}2\cos(h_1 + 168°)|$

Where C_1, L_1 *and* h_1 are the values of standard.

CIE 94 (1994.)

The CIE 94 equation is expanded by three factors for the lightness, hue and chroma/saturation parameters of S_L, S_C, S_H. The mathematical model includes three parameters, k_L, k_C, k_H, for lightness, hue and chroma/saturation values. According to the agreement, for standard conditions, the factor value should be unique and set to "1", but according to the agreement, for the needs of the textile industry, the accepted value of factor $k_L = 2$, and for factors k_C, $k_H = 1$. The precision of these factors was determined for the purpose of accurately determining the influence of certain color parameters in view of their role in the visual evaluation of color differences.

$$\Delta E = \left[\left(\frac{\Delta L^*}{k_L S_L} \right)^2 + \left(\frac{\Delta C^*}{k_C S_C} \right)^2 + \left(\frac{\Delta H^*}{k_H S_H} \right)^2 \right]^{\frac{1}{2}}$$

$$S_L = 1$$

$$S_C = 1 + (0{,}045 C^*)$$

$$S_H = 1 + (0{,}015 C^*)$$

CIEDE2000 (2000.)

It is based on the principles of the CIELAB system including modified mathematical expressions for the calculation of factor of brightness, tonality and saturation of S_L, S_C, S_H, and including a new mathematical formula of factor R_T that includes the values of tonality and chromaticity, thereby enhancing the applicability of the mathematical model, especially in the field of blue tones.

$$\Delta E_{00} = \sqrt{ \left(\frac{\Delta L'}{k_L S_L} \right)^2 + \left(\frac{\Delta C_{ab}'}{k_C S_C} \right)^2 + \left(\frac{\Delta H_{ab}'}{k_H S_H} \right)^2 + R_T \left(\frac{\Delta C'_{ab}}{k_C S_C} \right) \left(\frac{\Delta H'_{ab}}{k_H S_H} \right) }$$

❑ DIFFERENCES vs. TOLERANCES

✓ According to CIE established tolerances, which are accepted by the ISO standard for usage in textiles, but they can also be used in other branches such as graphic or architecture, are set as follows:

Maximum acceptable difference:

= 1,2 - 2 ΔC* 0,8 - 1,5 Δh = 0,5 - 0,8 ΔE* =1 - 2

❑ METAMERISM

✓ ***Metamerism*** is a phenomenon in which two or more observed coloured object, look identical under one light source, and by changing the light source, the observer, the size of the field of view and the geometry of the observation, there is a visible colour difference.

❑ INTERACTION OF SURFACE and COLOUR

- ✓ The visual experience of a coloured textile surface depends on the ratio and spectral characteristics of the reflected, absorbed and scattered part of the light, and this ratio is conditioned, among other things, by the specific surface structure of the textile.
- ✓ If in the light reflected with two equally colored, but differently surface-structured textiles, the representation of wavelengths does not change, but only the quantity, ie. the ratio of reflected and absorbed light changes, then there is a difference in perception of lightness and chroma (saturation) of observed surfaces, and there will be no change in color hue. However, if there is a change in the wavelengths distribution in the reflected part of the light in relation to the incident light, then there will also be a change in the color hue. The selective absorption, ie. the parts of the spectrum that will be absorbed, completely depend on the type and structure of the colored surface on which the reflection occurs.

❑ COLOUR ORDER SYSTEM

❑ Any systematic method of quantitative and qualitative classification of colors of the entire spectrum of colors can be called a system of color arrangement. Systematic classification of colors greatly facilitates communication about color and provides the possibility of realistic, exact and objective evaluation of the relationship between colors.

The most known colour order systems (ATLASES):

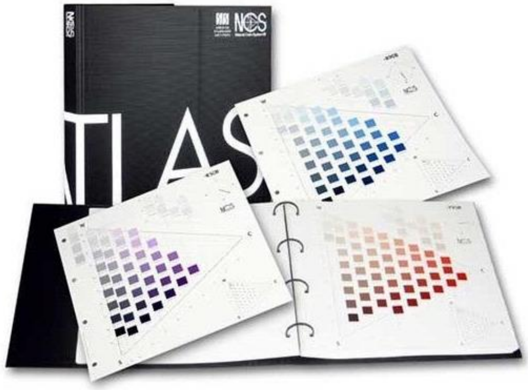
- ✓ MUNSELL
- ✓ NCS
- ✓ PANTONE
- ✓ RAL

MUNSELL Colour Atlas

PANTONE Colour Atlas

RAL Colour Atlas

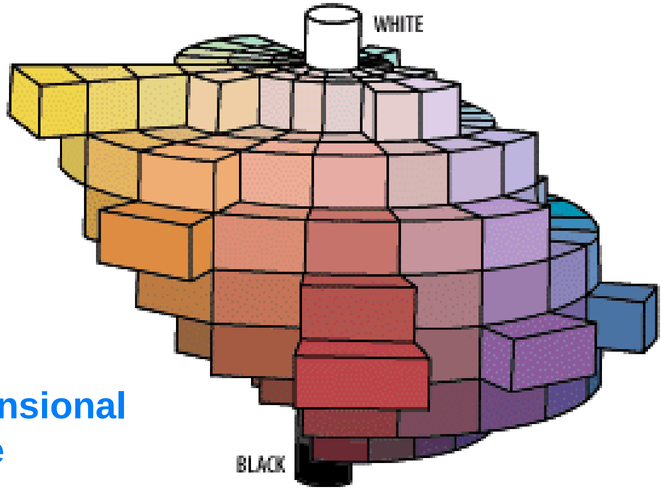
NCS Colour Atlas



❑ MUNSELL‘s Colour Atlas

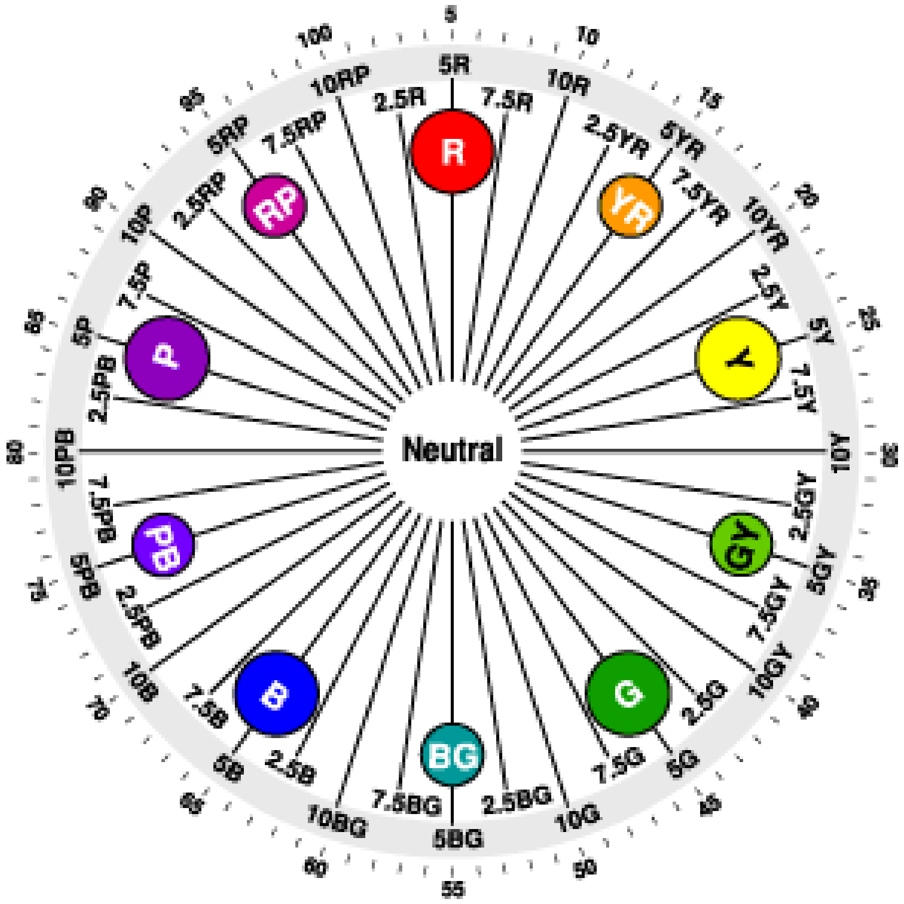
- Munsell arranges his system on the principles of human visual perception of colour. According to its specific arrangement, it is very close to the principles of visualization, which is why it is still in use today. It is considered to be the base for development of modern colour systems whic are based on numerical colour evaluation and systematization with respect to three basic colour parameters: lightness, saturation (chrome) and hue.
- The systems proposed and published before Munsell's were based on pure theoretical considerations and assumptions, which is why none of them stayed in practical use. Primarily because none of them was based on scientific experiments and examinations of the principles of human visual perception.
- **Before Munsell, the relationship between the basic parameters of color - hue, lightness and chroma (saturation), was not understood and could not be fully explained**.

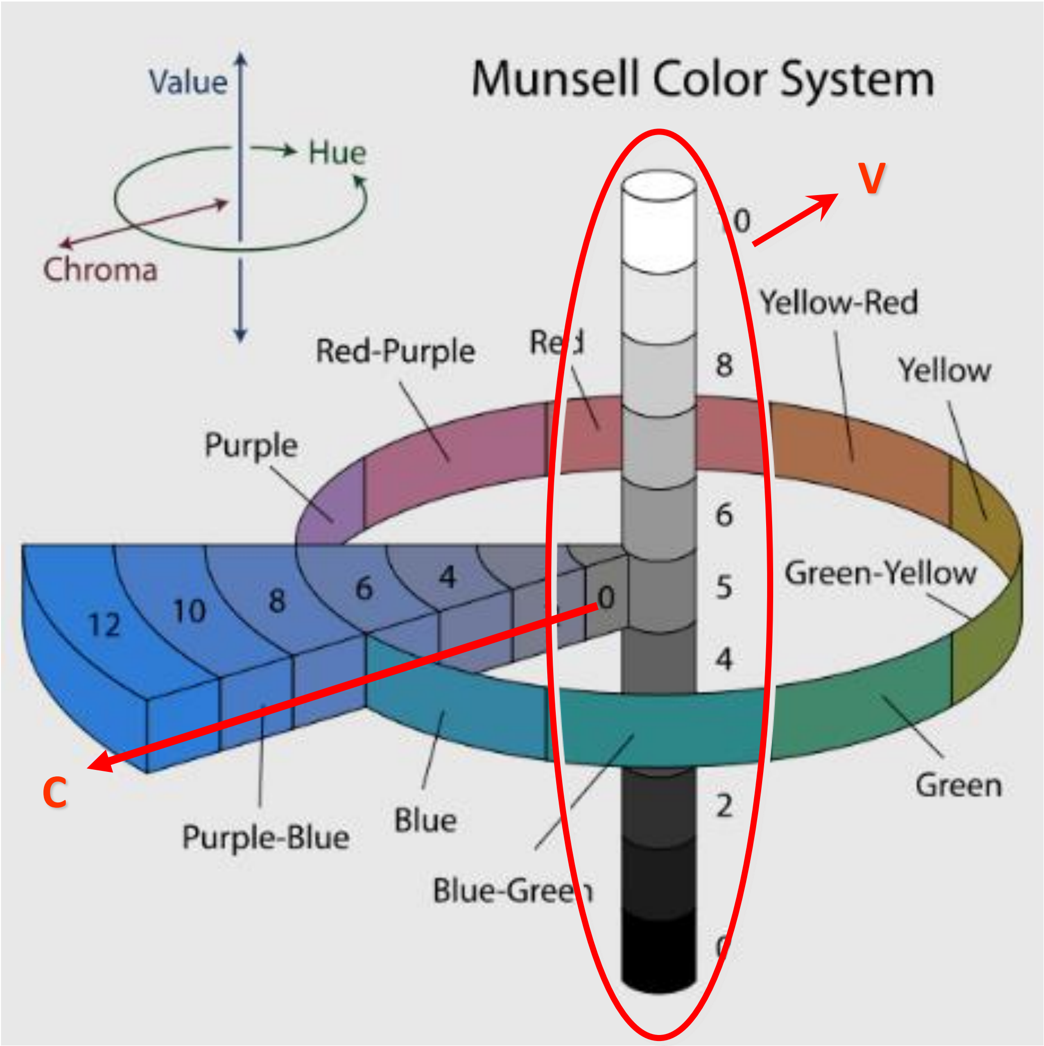
- In 1915, Munsell introduced his system in three dimensional sphere which featured 15 colour charts consisting of several hundred colour chips arranged according to the three characteristics of hue, lightness (value), and chroma. He called this sphere a ***"colour tree"***. Munsell discovered that the hue, lightness (value), and chroma cannot to be kept perceptually uniform, and that three dimensional colour sphere cannot be forced into a regular shape. The reason is that the human visual system does not recognize the same number of shades for every spectral colour. So Munsell was the first who confirmed that the colour three – dimensional space which corresponds to human colour vison is asymmetrical.



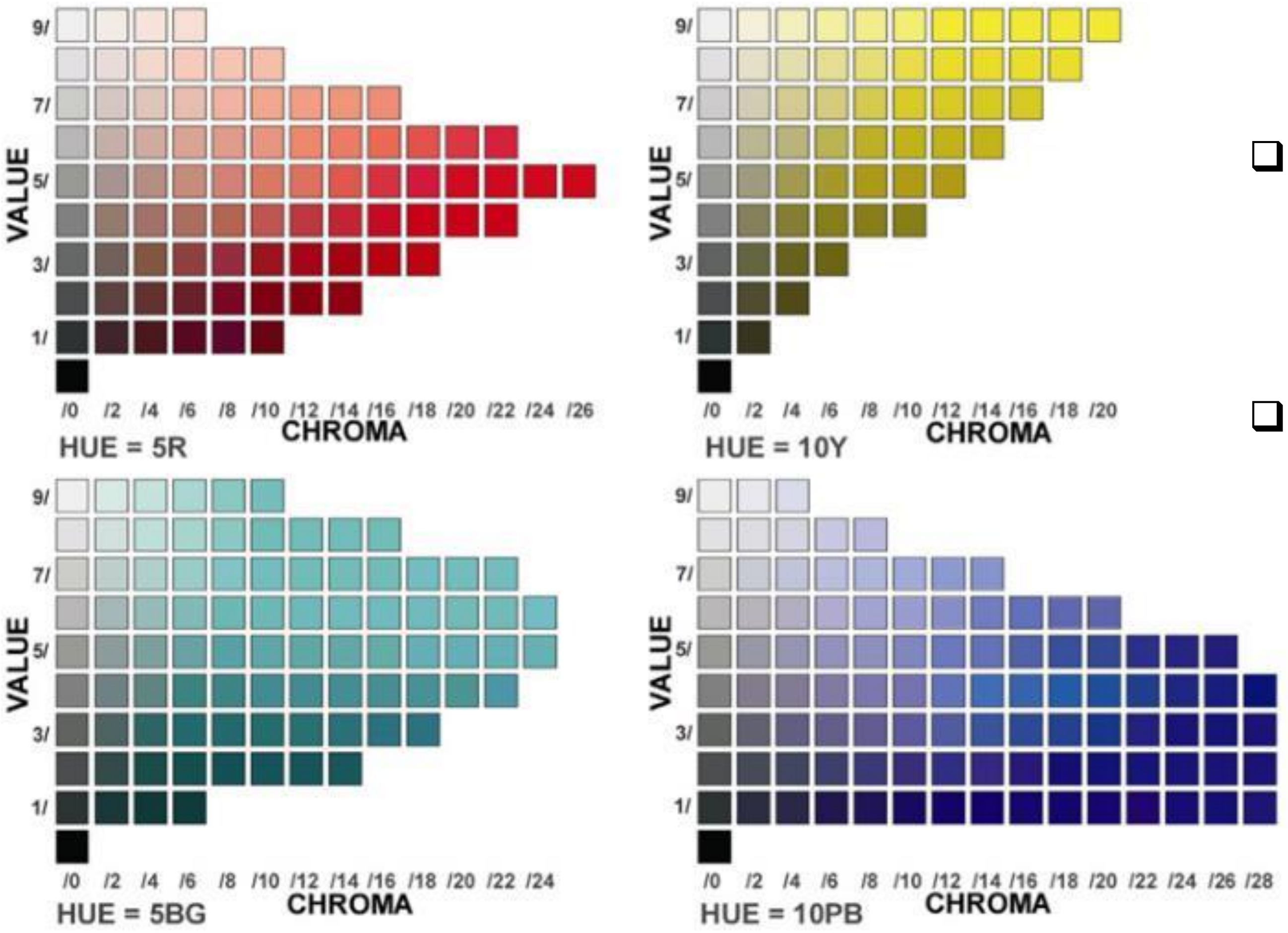
Henry Munsell's three dimensional asymmetrical sphere

- Munsell‘s hues are defined around horizontal circles and are divided into 5 main hues: **R**ed, **Y**ellow, **G**reen, **B**lue, and **P**urple, along with 5 intermediate hues: Red-yellow ***YR***, green-yellow ***GY,*** blue-green ***BG***, blue-purple ***BP***, red-purple ***RP***.
- For example, primary red would be ***5R*** since it stands at the main point of the red segment. ***2.5R*** would be a red tending more toward red-purple, while ***7.5R*** is a red tending more toward yellow-red. The red that stands at he mid-point between the red and yellow-red segment is ***10R***.

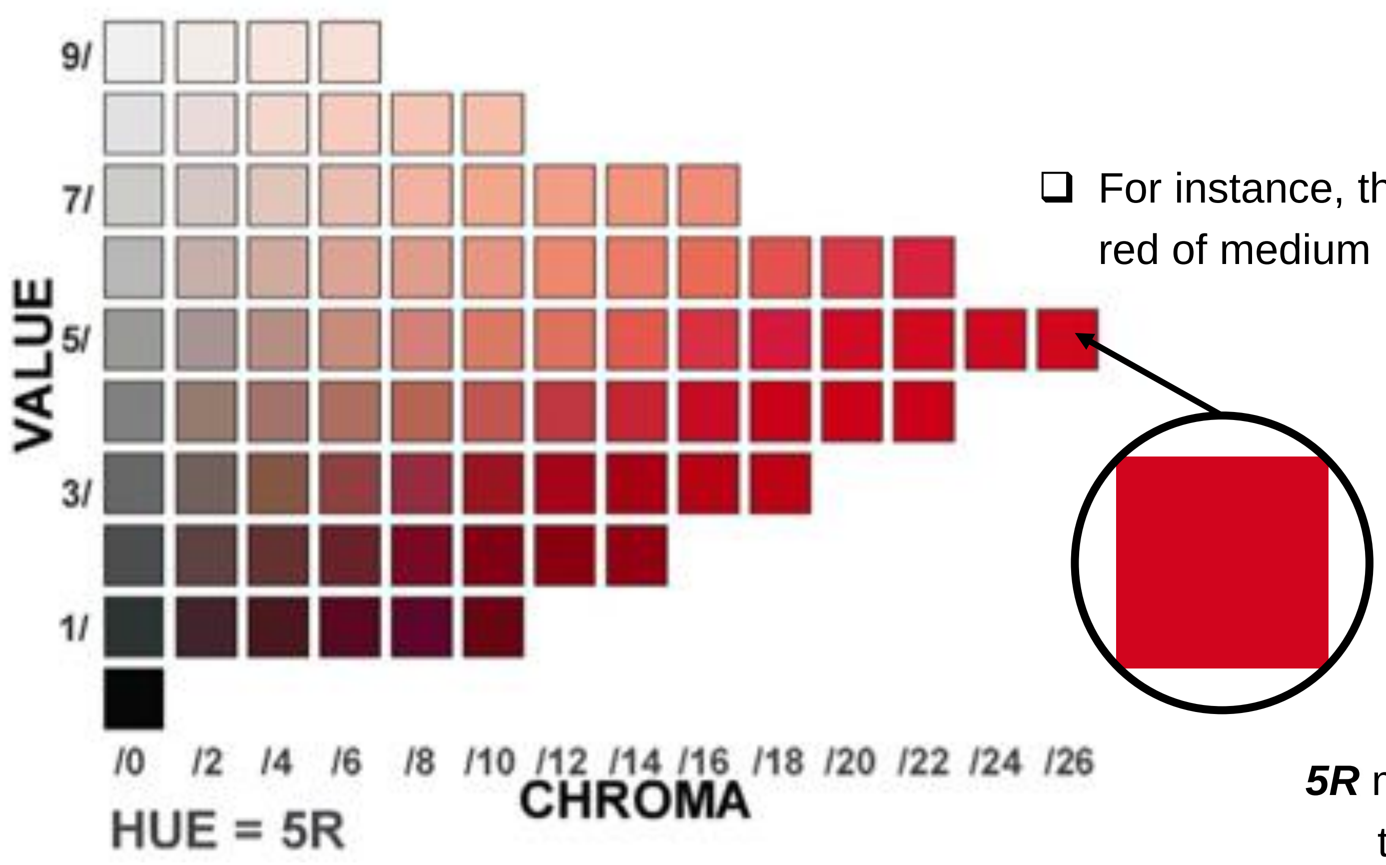




- ✓ ***Value***, or lightness, varies vertically along the color solid, from ***black*** (***value 0***) at the bottom, to ***white*** (***value 10***) at the top. Neutral grays lie along the vertical axis between black and white.
- ✓ ***Chroma***, measured radially from the center of each slice, represents the “purity” of a color, with lower chroma being less pure (more washed out, as in pastels). There is no intrinsic upper limit to chroma. Different areas of the color space have different maximal chroma coordinates.



- Examples of charts for four colours-yellow, red, blue-green and blue, described in Munsell‘s hue, value (lightness) and chroma values.
- A color is fully specified by listing the three numbers: ***hue, value, chroma***



- For instance, this sample of fully saturated red of medium lightness would be:

5R 5/26

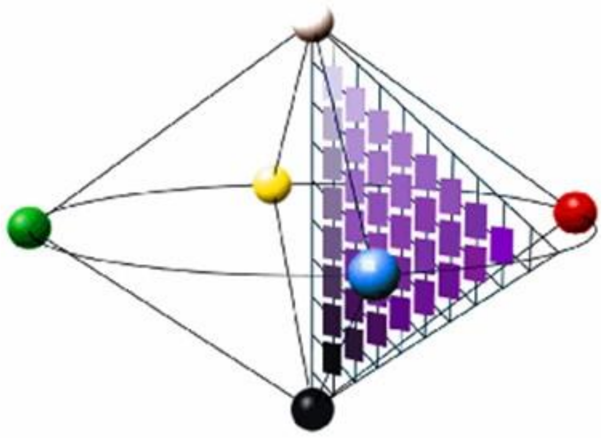
5R meaning the red that stands at the mid – point of the red segment

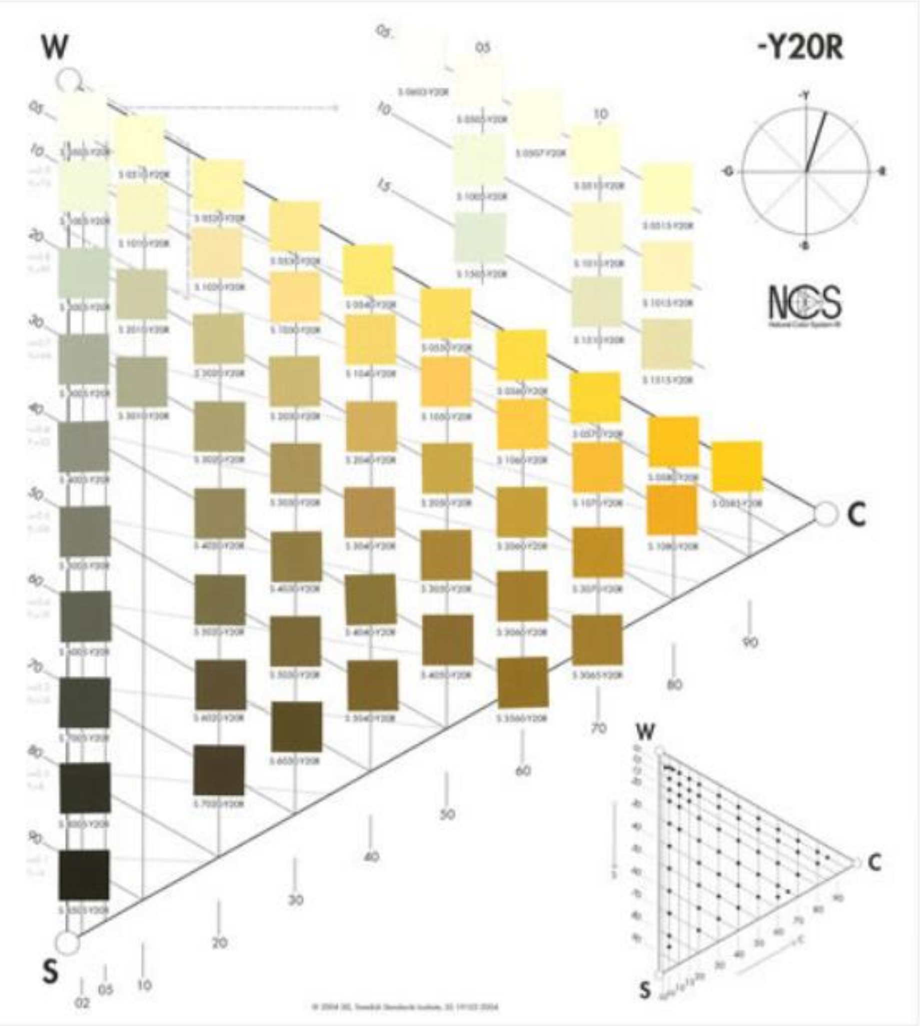
5 meaning medium lightness

26 meaning chroma

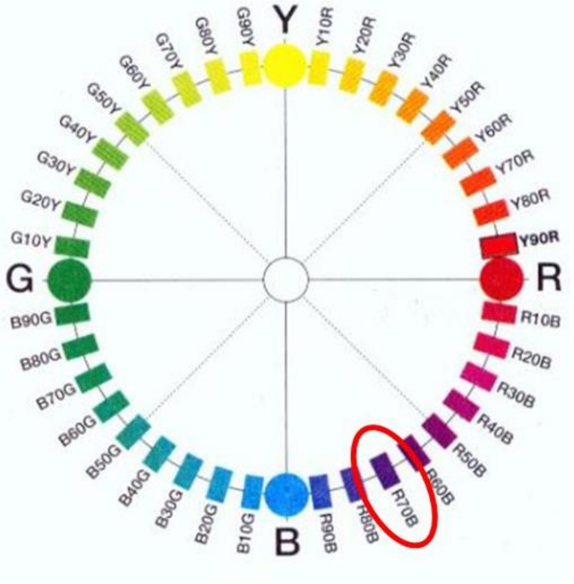
❑ NCS Colour Atlas

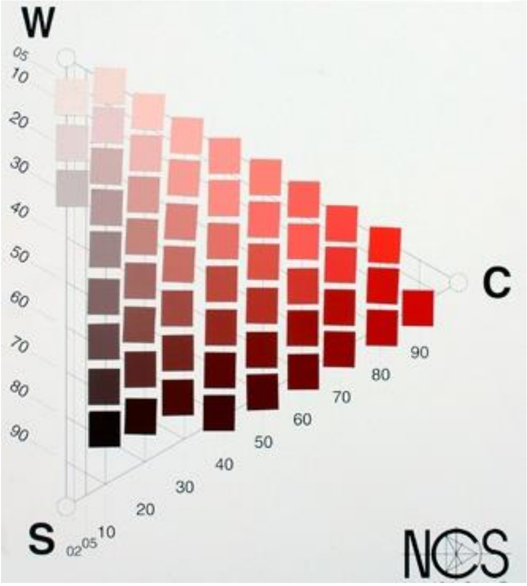
- ❑ The ***Natural Color System (NCS)*** is published by the Scandinavian Colour Institute of Stockholm, Sweden. It is based on three color dimensions: ***hue***, ***lightness*** and ***chroma***.
- ❑ ***NCS*** uses a three – dimensional colour space, based on four elementary colours (red, blue, yellow, green) which are placed horizontally at four equal steps of a circle. The third dimension is given by a line running from white to black through the centre of the circle.



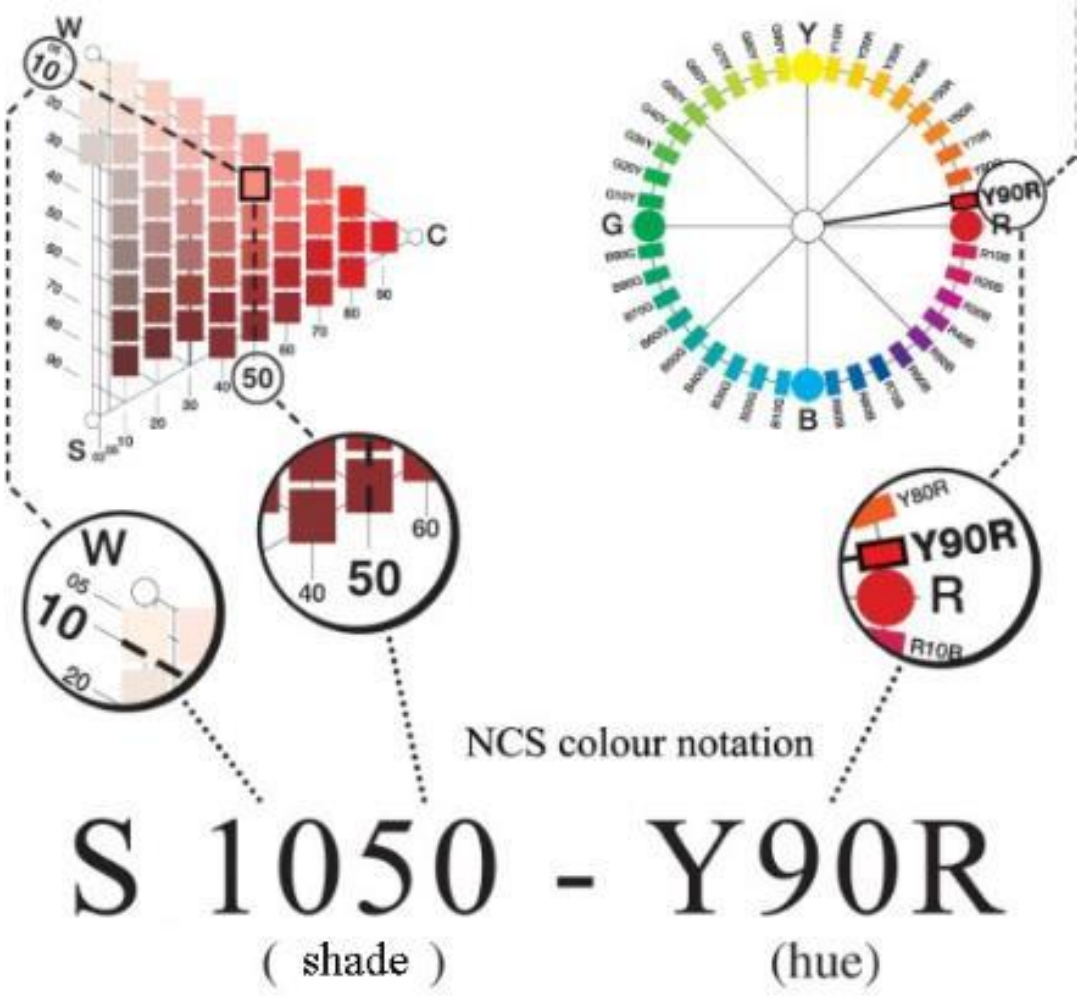


- The hue in NCS is characterised by the relative amounts of the two primaries hues that make up the colour.
- Thus in the red to blue quadrant the hue code ***R 7O B*** refers to a hue with a ***30% resemblance to pure red***, and a ***70% resemblance to pure blue***.





- All the colours in the NCS System have a percentage of ***Whiteness*** or ***Blackness***, and this is best illustrated using the NCS Colour Triangle. The NCS Colour Triangle is a vertical slice through the NCS Colour Solid. In the equilateral triangle the corners defines pure white (W) at the top, pure black (S) at the bottom and the perfect chromatic colour at the side.
- ***C*** stands for maximum colour intensity or ***Chroma***, ***W*** stands for ***White*** and ***S*** for ***Black***. The content of white or black in observed colour sample is defined in numerical values from ***100 (meaning 100% of black)*** till ***0 (meaning 0% of black – meaning white).***



- Using the NCS Colour Notation it is easy to define the appearance of a colour.
- In the example ***1050*** indicates the shade of the colour. The shade describes the relationship of the colour to Black (S) and to maximum colour intensity or Chroma (C).
- 10 means that the colour contain a minimal amount of black, and colour intensity or Chroma (C) is 50.
- The Hue, Y90R, describes the relationship of the colour to the Chromatic Elementary Colours, in this case Y and R. ***Y90R means Yellow with 90% Redness.***

PANTONE Colour Atlas

- In 1963, Lawrence Herbert created an innovative system for colour matching and identification, aiming in solving a problem of achieving a satisfactory colour match and reproduction for graphical artists. which consisted of a large number of small cardboard sheets. This resulted in creation of a first Pantone colour system referred to as the Pantone Matching System, or the PMS system. It's goal was to allow designers to 'color match' specific colors when a design enters production. This system was widely adopted by graphic designers and reproduction and printing houses and is still used today to specify colors for a wide range of industries.
- ***Pantone Colour System*** is a standardized color matching system, utilizing the Pantone numbering system for identifying colors. By standardizing the colors, different manufacturers in different locations can all reference a Pantone numbered color, making sure colors match without direct contact with one another.

- Today, Pantone colour systems are recognizable all over the world as universal language of precise and standardized colour communication used by designers, producers, resellers and final users. The importance of Pantone systme can be seen in a fact that Scotland, Canada and USA standardized the colours of their national flags according to Pantone system. For example, the blue colour on Scotland‘s national flag is standardized as “Pantone 300” colour.
- Also, numerous companies standardized the colour of their logos and trademarks using the Pantone colour system – Tyffani, Louboutin, Coca – Cola and among them the telecommunication company “T – mobile” whic is a telephone company also in Croatia.

Pantone Rhodamine Red; Pantone Cool Gray 7

- ***Pantone In textiles:***
- The ***PANTONE FASHION + HOME*** Color System is a vital tool for designers in the apparel, home furnishings and interior design industries for selecting and specifying color used in the manufacture of textiles and fashion.
- The System – consisting of 1,925 colors in cotton or paper format – is ideal for assembling creative palettes and conceptual color schemes, and for providing color communication and control in the manufacturing process.

- Examples of defining a colour in fashion design by using Pantone Fashion + Colour system

The red planned for the turtle neck shirt to be produced in is:

Pantone 19 – 1764

The green chosen for the trousers on this picture is:

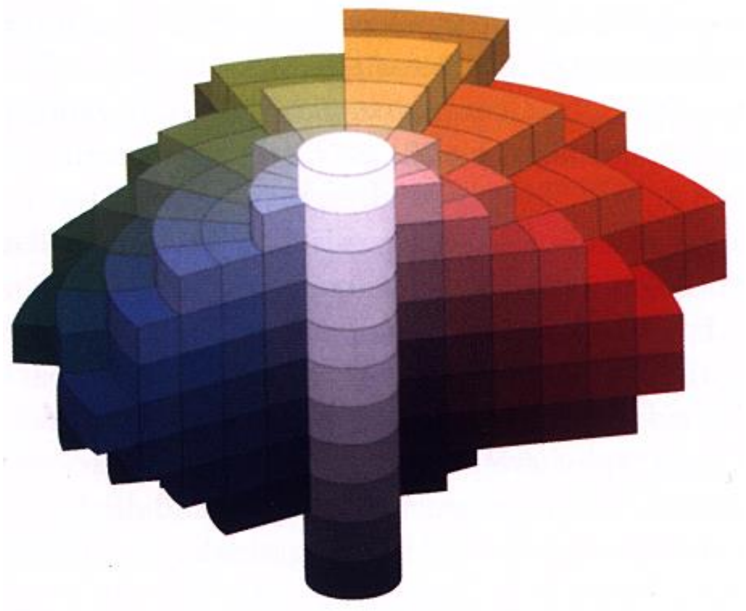
Pantone 18 – 0538

The gray dominating in design shown on picture is defined as:

Pantone 14 – 1107

Co-funded by the Erasmus+ Programme of the European Union

❑ RAL Colour Atlas



- In 1927, the German State Commission "Reichsausschuß für Lieferbedingungen und Gütesicherung" (State Commission for Terminology and Quality Assurance) published the first version of the system - a collection of 40 colored samples with a proposed nomenclature and classification, called "RAL 840".
- In 1993, the "RAL DESIGN" system was released - today the most popular RAL system in practical application, intended for design and architecture. The RAL DESIGN system, although based on a collection of colored samples, belongs to the group of objective systems because the color coding in the RAL DESIGN system is based on the settings of the 1976 CIE system (CIELAB).
- Colored samples were classified on the basis of three basic psychological attributes of color according to the CIE system: lightness ***L****, (chroma) saturation ***C****, and hue ***h****.
- For example, a sample labeled: 355 50 40 defines the following values: H = 355 (red), L = 50, and C = 40 (saturation).

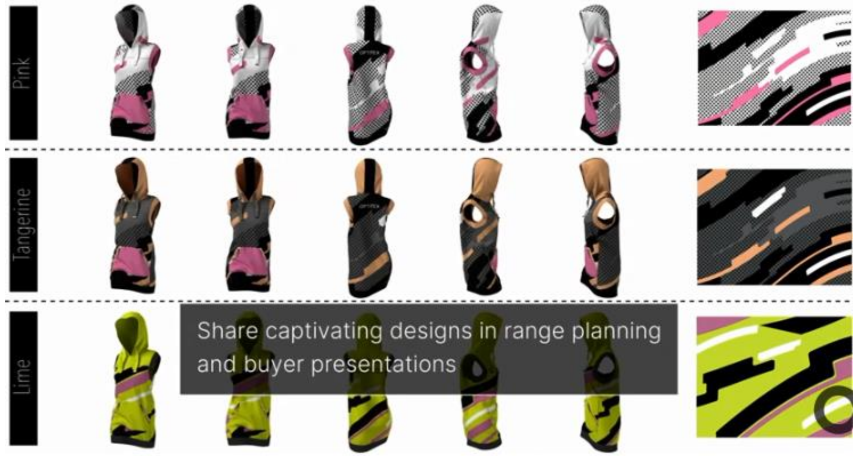
- The ***hue*** parameter is defined according to the CIELAB system, by values from 0° to 360°. The samples are placed in a circle around the central vertical, which defines the gray scale, ie defines the division of colored samples by lightness. The chromaticity (saturation) of the colored samples is lowest along the vertical axis and increases with distance from the vertical axis of the gray scale.
- In the RAL atlas, for each ***hue***, a series of patches are defined in different lightness and chroma values. The vertical axes represent the lightness levels and the horizontal rows represent the change in chroma for given lightness.
- Brightness values are defined on a scale from 0 - 100, also according to the CIELAB system, in the range of 5 to 10 units. Chromaticity values were defined in the same range.

✓ Color and Pattern Visualization

OPTITEX

3D Collaboration – From Concept to Production

- ❑ Draping and movement simulation
- ❑ Pattern positioning
- ❑ Pattern variation
- ❑ Fabric and textures simulation



- ❑ Visualizing garment in various materials, colors and patterns to get the visual properties of virtual sample.

- ❑ Displaying styles in high quality rendering mode and viewing designs in an accurate, true to life virtual sample.

❑ PANTORA Material Hub, part of X-Rite Total Appearance Capture ecosystem

- ❑ Module for real materials migration into the digital form.
- ❑ Setting for measuring and modelling the appearance characteristics of a physical material with high level of accuracy
- ❑ Enabling unmatched realism and efficiency in virtual design.

- ❑ Capturing physical appearance properties such as color, texture, gloss, translucency and transparency in a digital format.
- ❑ Simplifying the maintenance and upkeep of samples by utilizing digital material libraries.
- ❑ Eliminating ambiguities with precise accuracy to improve product quality and communication with stakeholders to reduce design approval cycles and accelerate time to market.
- ❑ Reducing the amount of time spent manually adjusting and correcting scanned materials.
- ❑ Experiencing more accurate renderings and improved product quality.