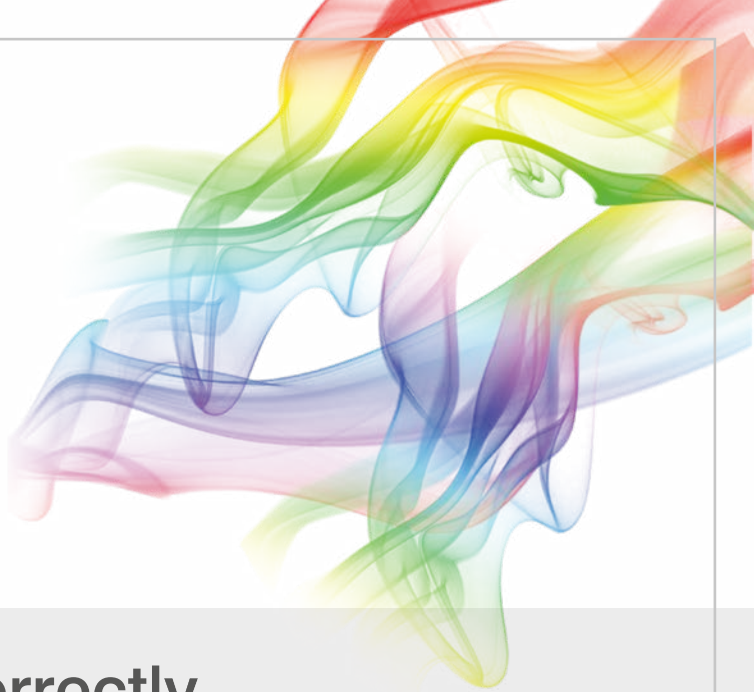
MICRO-EPSILON

Basics of colorimetry

Guide for industrial color measurement

What is **color?**



Color is individual, visual sensation elicited by light.

Color impression is subjective and depends on age, sex and daily mood, while factors such as illumination, background and surface structure also play an important role.

A human has no "color scale". Our brain creates an individual color impression making impossible adequate color description and documentation. Perceived colors are produced by receptors on the retina. Approx. 6 million cones are responsible for color perception and approx. 120 million rods for light/dark differentiation.

How to measure **colors correctly**

In order to receive constant results, a reproducible measuring method with the following conditions is required:

Please note:

- The sample surface must be as clean as possible. Finger prints, scratches, dust and residues of cleaning agents distort the measured results.
- Curved surfaces: always measure at the same location on the target with the least amount of curvature to achieve a reproducible result.
- Make sure that the sample is optimally positioned. If the distance from the sample changes slightly the measurement results will be influenced.
- Constant surface temperature is important for comparable results as different temperatures can lead to deviations. Samples in best quality should be qualified as representative master.
- Regular calibration is a prerequisite for reproducible results and should be performed under the same ambient conditions prevailing during the subsequent measurement.

Reproducible measuring methods and conditions

- Definition of sample (body or light)

- Definition of measuring points

- Definition of permissible tolerance

- Measurement conditions to be defined:

- Color space / color values (L*a*b*, XYZ, Luv, …)
- Distance models (ΔE, ΔEcmc, cylinder, box …)
- Illuminant (D50, D65, A or others)
- Standard observer (2° or 10°)
- Measurement geometry (specular or diffuse illumination)
- Measurement mode (reflection in reflex mode or transmission in transmitted light mode)
- Number of measurements

- Referencing with white/black/green standards

Only measurements performed under the same conditions are comparable.

Ensure constant measurement conditions.

Basics of color measurement

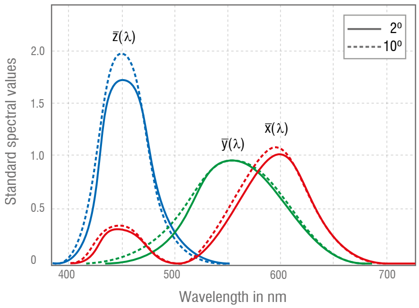
In order to create a basis for worldwide color communication and standardized color measurement systems, the CIE (Commission internationale de l'éclairage, International Commission on Illumination) was founded in 1931 and is responsible for monitoring and inspection of internationally recognized color values. The observer was defined (see "Standard observer") in a study based on individual color impression.

Furthermore, light sources such as fluorescent lamps, candles, the sun etc. were defined as illuminants. If a sample is measured using a color measurement device, the factors illuminant and observer are standardized, adjustable parameters with international validity. The color perception of the test persons was defined in the standard spectral sensitivity functions $\bar{x}$ (long-), $\bar{y}$ (medium-) and $\bar{z}$ (short-wave).

Color assessment based on:

- **Hue:** Color differentiation e.g. red, green, blue, yellow, etc.
- **Brightness:** Intensity of light perception, color appears darker or brighter
- **Colorfulness:** Intensity of the color compared with a gray color (not colored) with the same brightness
- **Saturation:** describes the relation between colorfulness and brightness

This is how each perceivable color can, due to its characteristics, be assigned an exact location in a color space and be communicated worldwide.

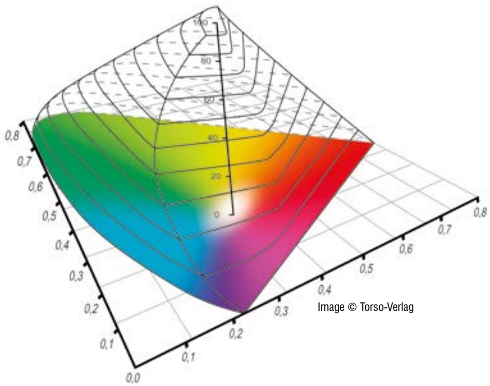


Spectrum

We perceive color stimulus between 380nm violet and 780nm red and can distinguish up to 10 million color shades.

Color spaces

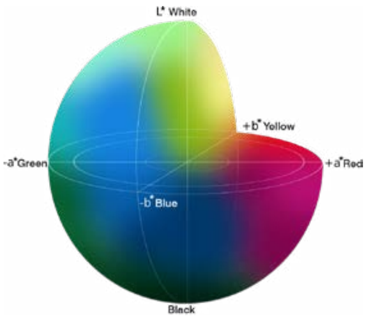
The human eye has three color receptors. This is why 3D color models are used in order to clearly identify colors and to compare these with other colors (see color distance). In the industry, particularly the L*a*b* color space has become established.



xyY color space

Standard color space CIE 1931 (xyY color space)

This color space is based on perceived color in human color vision.
(very large green and small blue/red range).
x and y = color vectors describing hue and saturation
Y = value (brightness) scaled from 0 to 100
W = white point (x=y=z=1/3)
Spectral lines = "pure" colors
Black body curve = color as temperature of an ideal, black radiator
Suitable for testing green and white LEDs.



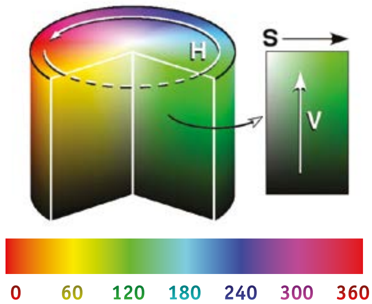
L*a*b* color space

Standard color space CIELAB76

The L*a*b color space comprises all colors perceptible to the human eye. In this 3D color model, each hue is described with approximately the same volume of space. The L*a*b* color space has established itself in the industry and is used by device manufactures for color inspection.
Each color is described by the color location (L*; a*; b*).
L* = lightness (black = 0; white = 100)
a* = green/red colors (green = -100; red = +100)
b* = blue/yellow colors (blue = -100; yellow = +100)

HSV/HSI color space

The colors in the HSV color space are defined by hue, saturation and brightness combining several color models such as HSV/HSL/HSI.
Each color is defined by the color coordinates (H, S, V)
H= Hue (red = 0°; green = 120°; blue = 240°)
S= (Saturation) Colorfulness (neutral gray = 0%; „pure“ color = 100 %)
V= (Value) Brightness
I = (Intensity) Light intensity (dark = 0%; very bright = 100%)



HSV/HSI color spaces

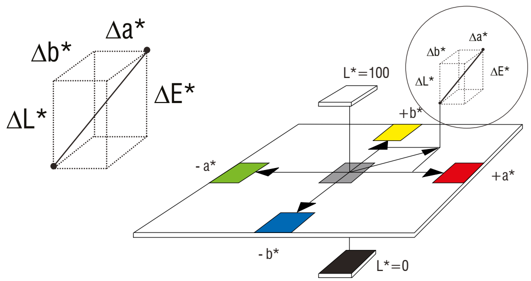
Color distance ΔE

The larger the difference between the colors within the color space, the more clearly the difference can be perceived with the human eye. This is defined as ΔE color distance.
Delta E; ΔE; dE = is a metric for the perceived color distance between colors (DIN 5033)

$$\Delta E = \sqrt{(L^*_p - L^*_v)^2 + (a^*_p - a^*_v)^2 + (b^*_p - b^*_v)^2}$$

ΔE of 11.61 corresponds to the difference between sample (p) and comparison (v)

$$\Delta E = \sqrt{(60^*_p - 55^*_v)^2 + (-38.6^*_p - (-30)^*_v)^2 + (-46^*_p - (-52)^*_v)^2} = 11.62$$



Sample (p)

Comparison (v)

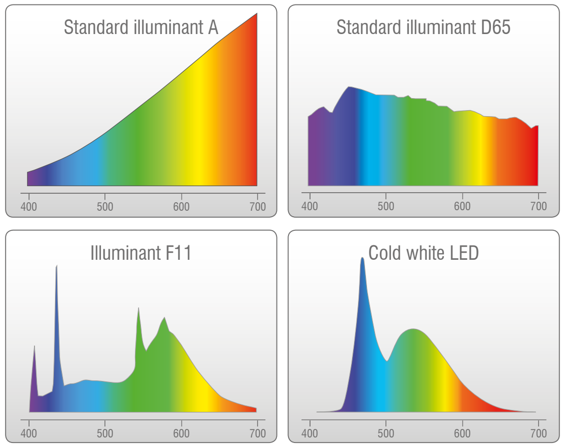
Interpretation:

ΔE > 5	Large color difference
ΔE 0.5 … 1	Limits of human perception
ΔE < 0.3	Required by the paper industry
ΔE < 0.1	Required by the automotive industry

Standard illuminants and light sources

Standard illuminants are defined from 380 to 780 nm.

- **Illuminant A** = light bulb with 2865k
- **Illuminant D65** = medium daylight with approx. 6500k
- **Illuminant F11** = fluorescent lamp
- **Cold white LED**



Standard observer

There are two different types defined by three cone sensitivity curves:

2° standard observer (1931)

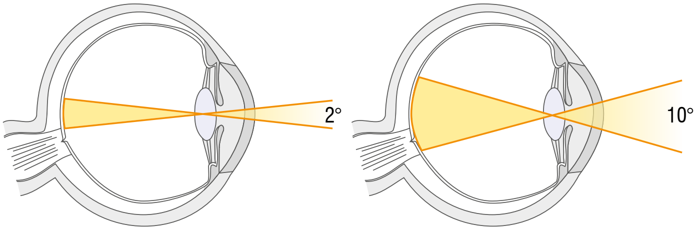
- Distance 30cm = 1cm visual field
- Focus onto small area of retina (macula of retina)
- Hardly corresponds to visual perception

At the end of an outstretched arm, an object the size of a thumbnail has an aperture angle of approx. 2°.

10° standard observer (1964)

- Distance 30 cm = 5 cm visual field (standard practice)
- Focus onto large area of retina (macula of retina + edges)
- Good correspondence with visual perception

At the end of an outstretched arm, this approximately corresponds to the palm without fingers. The sensitivity curves of the standard observers are standard spectral sensitivity curves/functions. The spectral values for $\bar{x}$ $\bar{y}$ $\bar{z}$ defined in DIN 5033 are the calculation basis for the chosen observer.



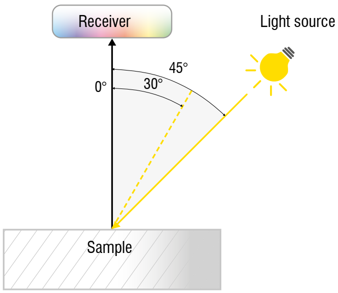
Standard observer

People perceive colors differently. In order to achieve perceptual uniformity, the International Commission on Illumination (CIE) stipulates spectral weighting functions.

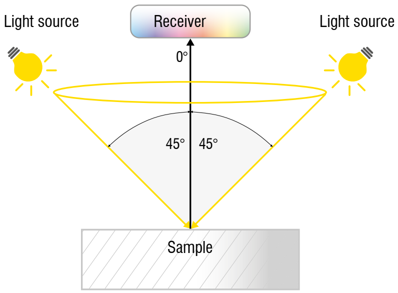
These functions describe how people perceive colors. They are based on experimentally determined sensitivity curves of the long-wave L-cone (X), medium-wave M-cone (Y) and short-wave S-cone (Z).

Measurement geometries

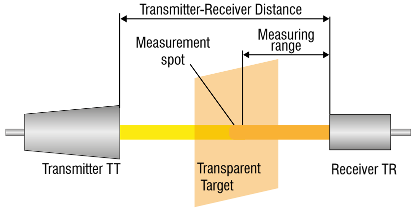
The measurement geometries described correspond to the color vision of the human eye.



Measurement geometry 30°x:0°; 45°x:0°
The sample is illuminated at 30°/45° and measured at 0°.



Measurement geometry R45°c:0°
The sample is illuminated at 45° and measured at 0°.
All-round lighting minimizes structural influences by the surface.
No orientation must be specified.



Transmission sensor with transmitter (TT) and receiver (TR) 0°:180°

General

Metamerism means that a pair of samples looks the same under one light source but different under another light source.

With **structured surfaces**, it is recommended to perform the inspection from all four directions (north, east, south, west on one side) and to calculate the average on different positions or to illuminate the specimen from all directions (ring illumination (R45°c:0°) and to measure only one position.

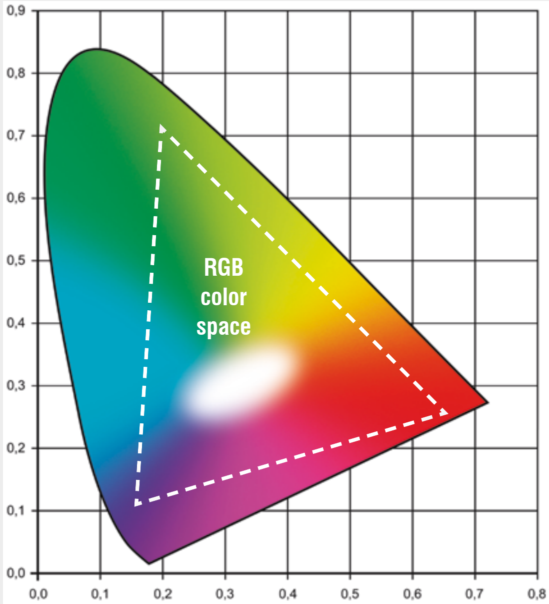
If the **samples are translucent**, a defined background or folding the sample should provide sufficient layer thickness for the inspection. You can alternatively use some illumination as background in order to inspect in transmission (0°:180°) mode.

The **average** is calculated with several measurements on different positions or only one position of the sample and by evaluating these values.

The **color temperature** refers to the temperature by which black bodies would have to be heated theoretically in order to emit light with the same color. Color temperature is measured in Kelvin (K).

The **RGB color space** combines the colors red (R), green (G) and blue (B) into one. It is an additive color space, i.e. all three colors as one result in the color white. Black color is produced when R/G/B = 0/0/0.

The RGB color space has established itself in the display industry but is of no interest for industrial measurement technology since not every color can be displayed and measured.



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