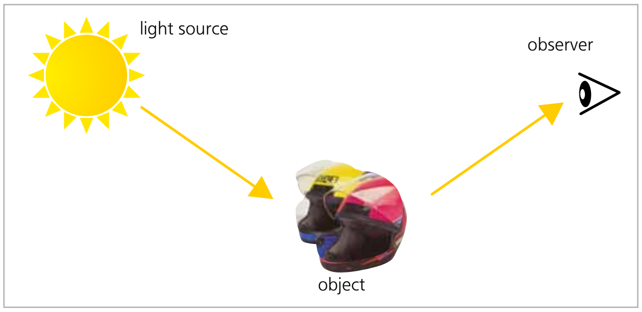
Introduction

Color Perception

Ten million! That is the number of different colors that we can distinguish. No wonder we cannot remember colors well enough to identify a particular shade. However, the quality criterion "color" is becoming more and more important in every industry. Uniform color influences customers' likes and dislikes. This is of particular importance when the individual components of the final product are manufactured at different company sites, or even more complicated when several suppliers are involved. Nevertheless, in the end the color must be right.

Visual color perception is influenced by different color sensitivities from person to person (mood, age, etc.), varying environments such as lightness and color, as well as the deficiency to communicate and document color and color differences.

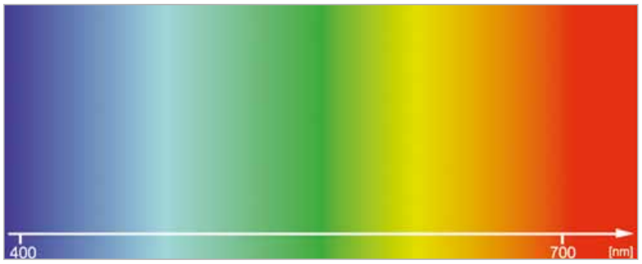
These shortcomings can only be solved by using color instrumentation with internationally specified color systems. This guarantees objective description of colored objects. Color perception is dependent on the interaction of three elements:



SOLID COLOR

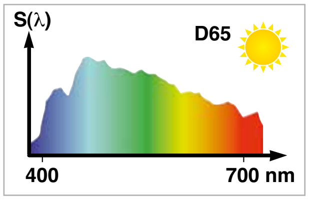
Light Source

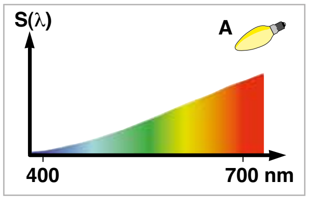
Color changes with the light source. Therefore, standard illuminants have to be agreed upon and used. The prerequisite of a light source to be usable for color evaluation is to continuously emit energy throughout the visible spectrum (400 to 700 nm).

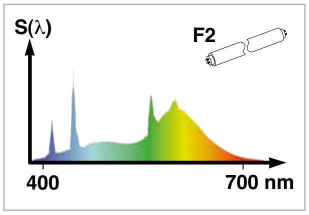


White daylight dispersed into the spectral colors (rainbow)

The CIE (Commission Internationale de l'Eclairage) standardized light sources by the amount of emitted energy at each wavelength (= relative spectral power distribution).
In practice, important illuminants are:
Daylight D65, C
Incandescent light A
Fluorescent light F2, F11

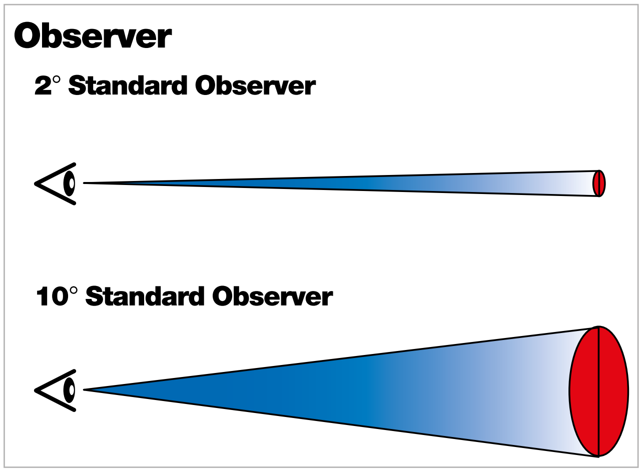






Observer

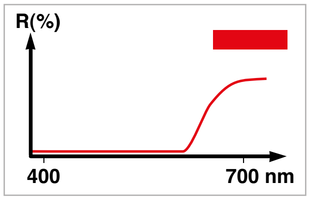
Without an observer there would be no color. Reflected light from a colored object enters the human eye through the lens and strikes the retina. The retina is populated with three different types of light-sensitive receptors: one which reacts to red light, another to green light, and a third to blue light. Together they stimulate the brain to produce the impression of color. To determine the sensitivity of the receptors, systematic visual tests were done by the CIE in 1931 and 1964. Based on the results, the 2° and 10° observer were standardized, representing a small and large field of view, respectively.

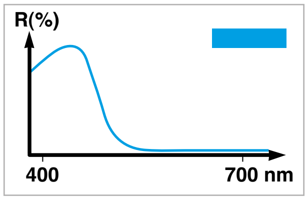


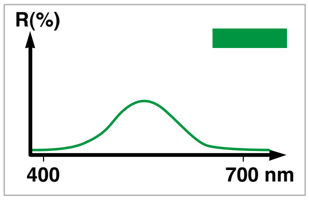
When viewing a sample, the eye integrates over a large area, which correlates best to the 10° observer.

Object

Light source and observer are defined by the CIE and their spectral functions are stored within color instruments. Optical properties of an object are the only variables that need to be measured.
Modern color instruments measure the amount of light that is reflected by a colored sample. This is done at each wavelength and is called the spectral data.
For example, a black object reflects no light across the complete spectrum (0% reflection), whereas an ideal white specimen reflects nearly all light (100% reflection).
All other colors reflect light only in selected parts of the spectrum. Therefore, they have specific curve shapes or fingerprints, which are their spectral curves.
In the following graphs, typical spectral curves for a red, blue and green sample are shown.





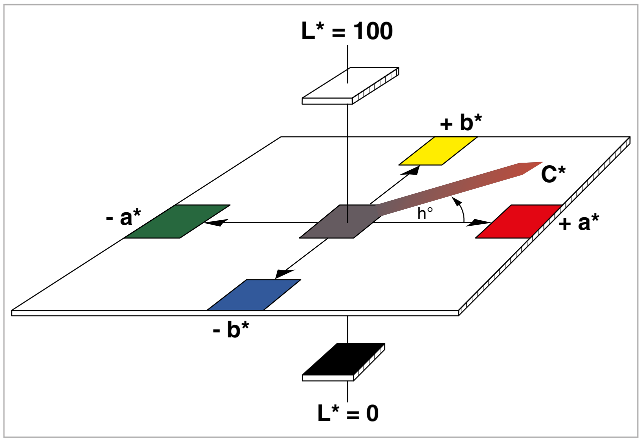


Color Systems

Color systems combine data from three elements:

- light source
- observer
- object

They are the tools to communicate and document color and color differences.
The system which is recommended by the CIE and widely used today, is the CIELab system.

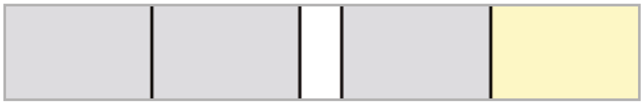


It consists of two axes a* and b* which are at right angles and represent the hue dimension or color. The third axis is the lightness L*. It is perpendicular to the a*b* plane.Within this system, any color can be specified with the coordinates L*, a*, b*. Alternatively L*, C*, h° are commonly used. C* (= Chroma) represents the intensity or saturation of the color, whereas the angle h° is another term to express the actual hue.

To keep a color on target a standard needs to be established and the production run is compared to that standard; a typical customer / supplier situation. Therefore, color communication is done in terms of differences rather than absolute values.
The total change of color, ΔE*, is commonly used to represent a color difference.

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

The same ΔE* value can be obtained for two sample sets, and yet look completely different:

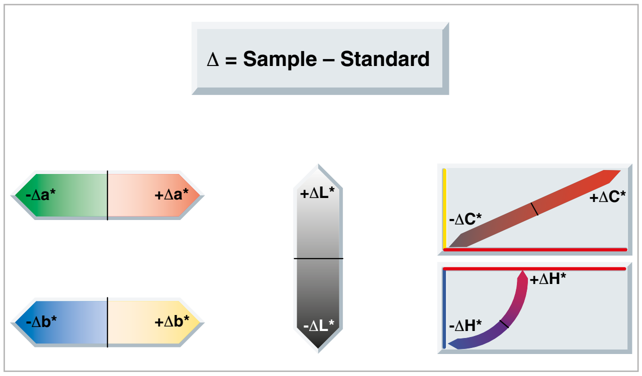


Sample Set 1 Sample Set 2

	Sample Set 1	**Sample Set 2**
ΔL*	0.57	0.0
Δa*	0.57	0.0
Δb*	0.57	1.0
ΔE*	1.0	1.0

To determine the actual change in color, the individual colorimetric components ΔL*, Δa*, Δb* or ΔL*, ΔC*, ΔH* need to be used.

The calculation and interpretation of the differences are done as follows:



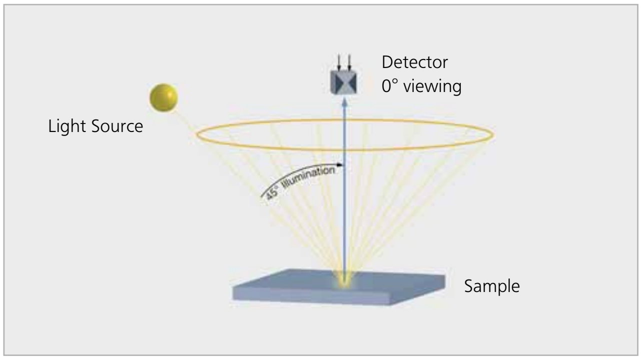
The color differences that can be accepted must be agreed upon between customer and supplier. These tolerances are dependent both on demands and technical capabilities.

Color Instrumentation

In industry, there are two classes of instruments used to measure color: 45/0 and sphere geometry.

Control color as you see it

The 45/0 geometry uses 45° circumferential illumination and 0° viewing perpendicular to the sample plane.
The circumferential illumination is essential to achieve repeatable measurement results on directional and structured surfaces.

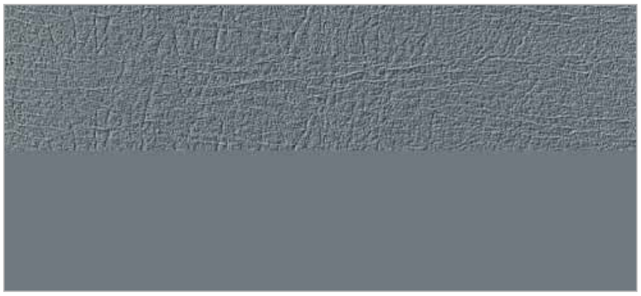


The 45/0 geometry simulates the normal condition used for color evaluation. For example, when we read a glossy magazine we position it to avoid the gloss from coming into our eye.
A high gloss sample with the same pigmentation is visually judged darker by the eye when compared to a matte or structured sample.
This is exactly what a 45/0 instrument measures:

Differences in gloss / texture → Color differences

On the automotive interior plaque, you will get a difference between the two structured sides: **ΔE* = 3**
Applications where it is necessary to have the agreement with the visual assessment are:

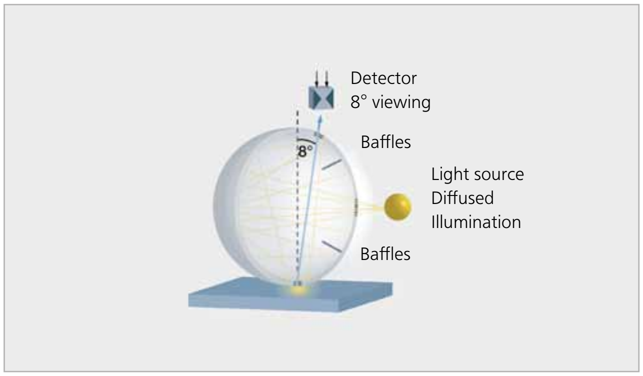
- Batch to batch comparison in production
- Assembly of multi-component products using different materials



Example: Automotive interior plaque – one material with different structures.

Control the hue of your color

A sphere geometry illuminates the sample diffusely by means of a white coated integrating sphere. Baffles prevent the light from directly illuminating the sample surface. Measurement is done using an 8° viewing angle.



A sphere instrument may be operated under two different measurement conditions:
specular included (spin) or specular excluded (spex)
In the "spin" mode, the total reflected light is measured:
Diffuse reflection (color) + direct reflection (gloss)
Color is measured independent of the sample's gloss or surface texture.

Differences in gloss / texture ↛ Color differences

On the automotive interior plaque, you will get no difference between the two structured sides: ΔE* = 0

Applications for measurements taken in "spin" mode:

- Color strength depending on dispersion time
- Weathering and temperature influence on color
- Color matching

In the "spex" mode, a gloss trap is used to capture the directly reflected light (gloss). This configuration simulates the 45/0 geometry. In case of medium to low gloss samples, deviations will occur between the 45/0 and the sphere spex configuration as the gloss trap does not completely exclude the specular component.

Summary

Only measurements taken under the same conditions can be compared. Therefore, it is necessary to note the following information in a color measurement report:

- Color instrument (geometry)
- Illuminant / observer
- Color system
- Sample preparation

BYK-Gardner offers a complete line of benchtop and portable spectrophotometers for color measurement.