Fundamentals of Colorimetry

Application Report No. 10e

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Fundamentals of Surface Colour Measurement

Introduction

Colours make the world colourful. All shapes, whether created by man or nature, are always combined with a typical colour. The functions of colours are not merely aesthetic but also communicative and symbolic: blue traffic signs are mandatory ones, a brown apple is certainly not fresh, and purple is the colour of royal dignity. Modern industrial products are considered branded goods only if they are recognized easily. One of their major characteristics is the typical colour of the product.

The term “colour” is used in various meanings. Colour may be the paint a painter applies to a canvas. Colour is also a characteristic of an object perceived by the eye.

Why Colour Measurement ?

Just like the spacial perception, colour perception is three-dimensional. That means, to describe colours better than in words (like rose-red, sky-blue) you must either give clear numerical information regarding e.g. lightness, shade, and saturation or use comparable information like RAL 9001 if adequate corresponding colour standards are available.

The difficulty of describing colour differences in words is easy to understand in view of the fact that the eye discerns more than one million shades. Colour perception is a subjective sensation created by the coincidence of a number of individual factors like age, mood and surrounding conditions.

If the colour of a product deviates from the one agreed or colours in serial products vary, such products are considered lowgrade. Even slightest deviations may provoke disagreement between buyer and supplier.

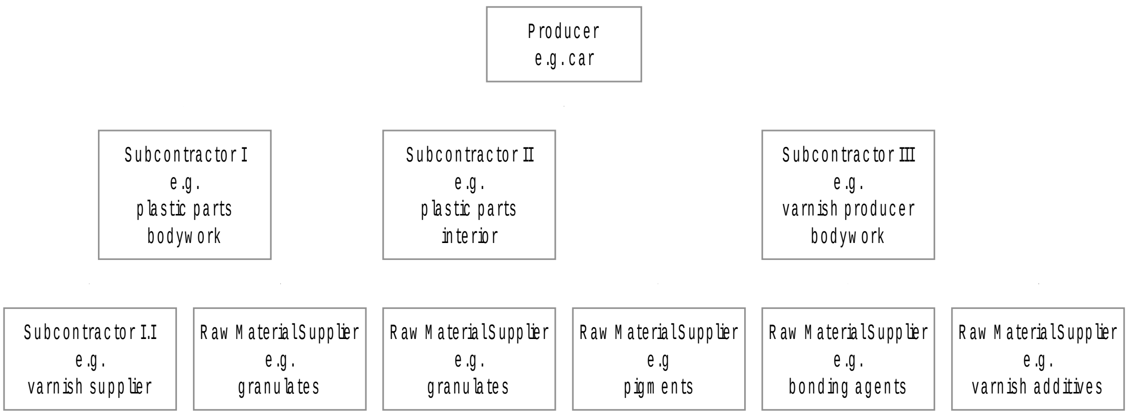


Figure 1: Production chain

Colour measurement saves money!

In practice many industrial sectors work together within the production chain with a clear separation between the stages, from the suppliers of raw material to the producer (fig. 1).

This figure reveals that all companies involved must co-operate very closely within such a chain, especially with regard to keeping the agreed and stipulated tolerances and standard values of the products. The receiving and outgoing goods departments of the member companies are the actual links in the chain. Selective use of colorimeters in these key departments helps to check colour conformity of semi-finished and finished goods in an indisputable way. Good co-operation betweenn the departments within each company is indispensable for smooth co-operation with other chain members. The links between the members of a production chain are virtually the same as those within an individual company.

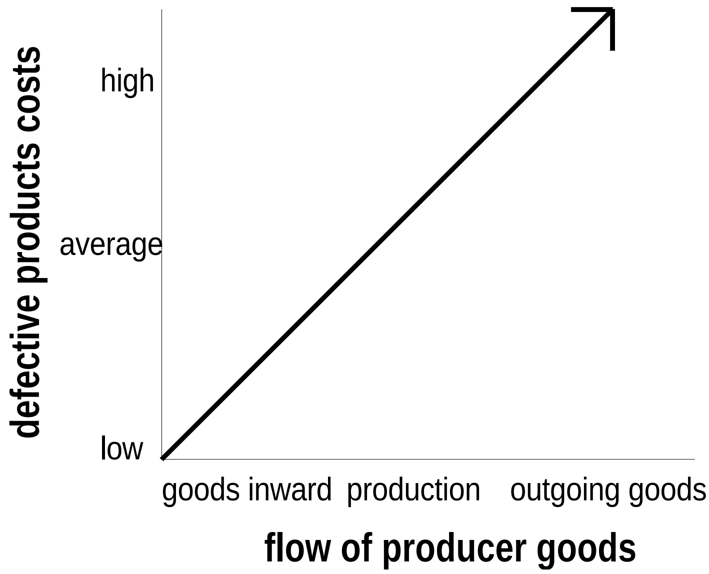


Figure 2: Defective products graph

The main objective of a production plant is to produce uniform and optimum quality at minimum costs. Therefore, it would not make sense to assign colour control to the outgoing goods department but to the receiving department. If colour differences are detected there, they can be handled by:

1.) Financial agreement with the supplier

2.) Manipulating your own production process to correct deviating colours.

Detecting a deviation from the agreed colour tolerance during the final inspection, i.e. after production, would increase costs. The goods must be reworked or offered at a lower price, if not rejected. Depending on the product, rejects may involve enormous disposal and environmental problems.

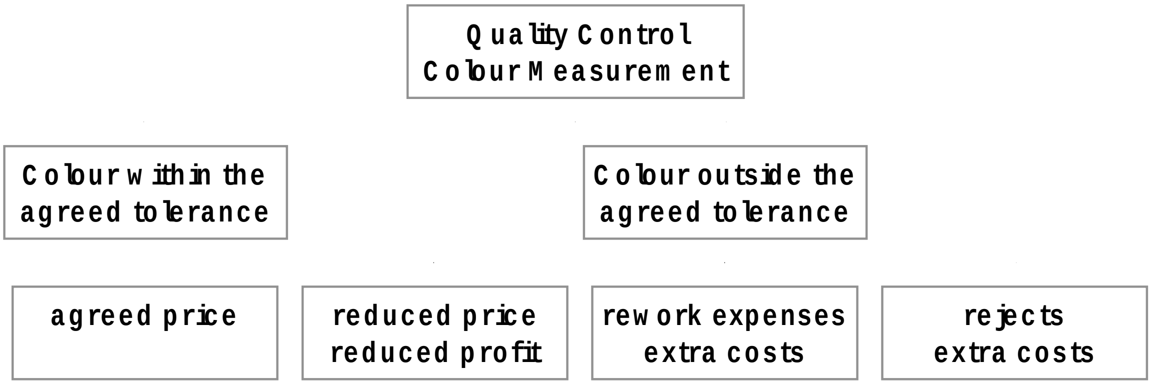


Figure 3: Process improvement by colour measurement

Colour measurement is not only useful to check incoming goods but also during production. Treatments like heating, drawing, grinding, flattening, drying, mixing etc. have decisive influence on the appearance of the product. At these production stages, colour measurement helps to optimize the process flow and keep costs low (fig. 3). Thanks to modern opto-electronic components, colour measurement is nowadays easy to handle and to understand - and less expensive than before. Nevertheless, inexperienced users should read the following fundamental information to learn what colour measuring technology is about and how to use it best in their specific field of application.

Fundamentals of objective colour measurement
As early as in 1931, colorimetric principles were stipulated on an international level by standardizing light sources (standard illuminants), standard observer and a colorimetric identification system known as CIE-colour system (CIE = Commission Internationale d'Éclairage). To be able to use the CIE-colour system, you should be familiar with the following definitions:

Colour perception
Colour perception is created by visible electro-magnetical radiation reaching the eye. In the retina, receptors transform this colour stimulus into electrical pulses which make the brain perceive the colour of the object seen. There are basically three ways of colour perception as shown in figure 4:

a) light source (primary light source),

b) transparent object (transmission),

c) reflecting object (reflection).

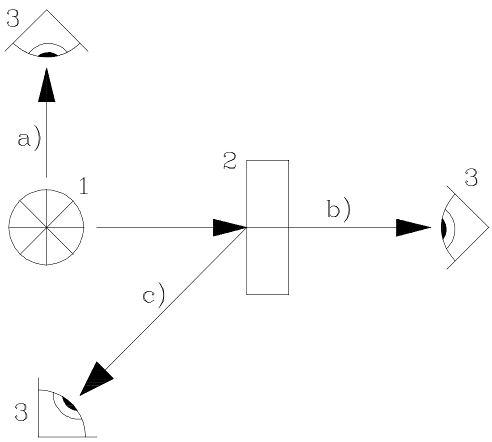


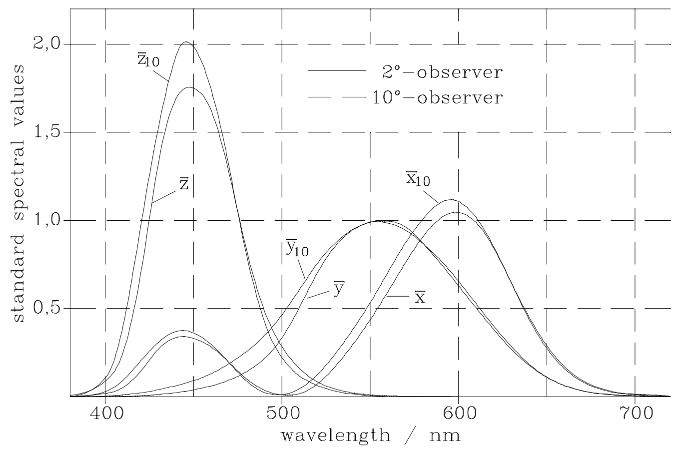
Figure 4: Ways of Colour Perception

The human eye

The human eye is a highly sensitive and complex sense organ, able to discriminate about a million of shades and detect even slightest deviations between reference and sample. For visual colour matching, however, the eye is not always reliable, because it is subject to changing surrounding conditions and observer's mood. Moreover, defective colour vision - which is nothing uncommon, affecting about 8% of males and 0.5% of females - is a drawback. The retina of the eye contains light-sensitive cells (cones) providing colour vision at daylight (light-adapted eye) and the so-called rods for vision in the darkness (dark-adapted eye). The sensitivity of the cones may be divided into three groups - red, green and blue. The rods do not contribute to colour vision. They can sense only differences in light and dark.

DIN 5033 part 2 defines the spectral sensitivities of the three cone types for the light-adapted eye (i.e. for daylight colour vision). In this connection, the term "colorimetric standard observer" is employed. The spectral sensitivities of the cones are called standard spectral functions (fig. 5) and defined by $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ or. $\bar{z}(\lambda)$ (λ = wavelength).

Figure 5: Standard spectral functions of 2° and 10° standard observers



But the statistical distribution of the rods and cones on the retina is uneven. In the centre, directly opposite the pupil, there are only cones which are increasingly replaced by rods towards the outer fringe. Therefore, colour perception changes with the size of the object observed. Due to the fact that the colour stimulus changes with the size of the observed area, a 2°-standard observer was introduced into DIN 5033 in 1931 and a 10°-standard observer in 1964. The 2°-standard observer assesses a coloured surface of coin-size at a reading distance of about 50cm, whereas the 10°-standard observer assesses a postcard-sized surface at the same distance. To distinguish the measured values from 2° and 10°-observers, the 10°-values are marked with an index (10).

How the light source influences colour vision

Characteristics and colour temperature of the light source play an important part in colour assessment. A red, yellow or blue light source is not suitable for colour assessment, because such an illuminant would always emit only a part of perceptible radiation which the illuminated object would then reflect. Colour temperature influences the whiteness of the light source. Standard illuminant A was defined as early as in 1931, corresponding to the spectral function of a 100W incandescent lamp at a colour temperature of 2800 Kelvin. The colour temperature of standard illuminant C is 5600 Kelvin, of standard illuminant D_{65} 6500 Kelvin. The eye perceives only the small share of the electro-magnetic radiation within the range of wavelengths between 380nm and 720nm. The relative spectral distributions S (λ) for the standard illuminants are defined in part 7 of DIN 5033. Figure 5 shows standard illuminants A, C and D65.

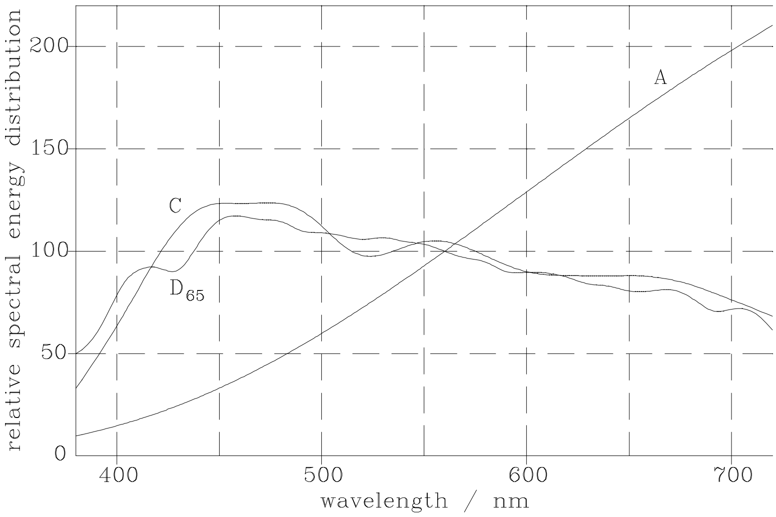


Figure 6: Standard illuminant

Sample reflections
As soon as light falls on a sample, the surface reflects a part of the incident light energy at once (surface reflection or gloss impression). This reflection may serve as a measure of the gloss impression of the surface. If the surface causes a diffuse and scattered reflection, it will be perceived as being matt. A regular surface reflection causes the impression of a glossy, high-gloss or even specular gloss surface. This kind of surface reflection amounts to around 4% of the incident light energy. An objective assessment of gloss (DIN 67530) is possible with gloss-meters or so-called reflectometers (see Dr. Lange Application Report No. 7).

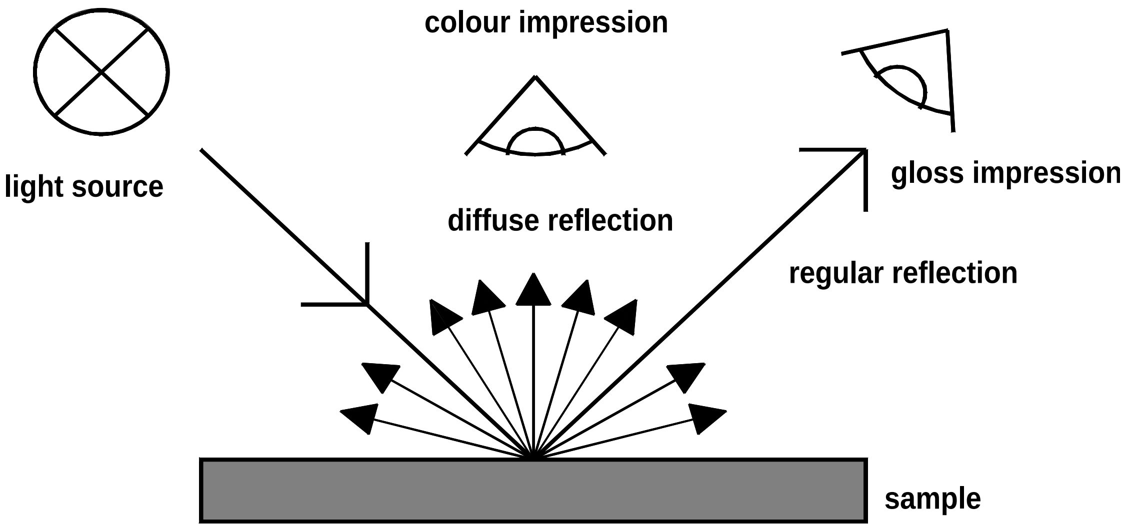


Figure 7: Surface reflections

The remaining share of the light beam penetrates the surface and reaches the colouring agents or colour pigments to be transformed into coloured light by absorption of scatter. This coloured light leaves the sample again in scattered or diffuse direction, thus providing its colour impression.

Colour matching methods
There are three basic colour matching methods:

- visual colour matching
- tristimulus measurement
- spectral method

Visual colour matching
In this method, the sample is compared visually, i.e. by eye, with a colour reference. The decisive drawbacks of the visual method are, among other things, the varying subjective assessment (defective colour vision of the colour matcher or adverse, varying light conditions) and difficult assignment when shades of sample and colour matching scale deviate due to red or green casts. Although ruling standards demand explicitly that this method be applied only to samples of shades similar to those of the reference, the expression “similar” leaves room for interpretation in practice.

Tristimulus measurement
In the tristimulus method, the light reflected by the sample is passed through colour filters and split up into its red, green and blue shares corresponding to the cone sensitivities and measured individually with photocells. The measured signals are termed reflectances Rx, Ry and Rz. They are employed to calculate the tristimulus values following equations (1) to (3).

$$X = a\ !\ Rx + b\ !\ Rz \qquad \textbf{(1)}$$

$$Y = Ry \qquad \textbf{(2)}$$

$$Z = c\ !\ Rz \qquad \textbf{(3)}$$

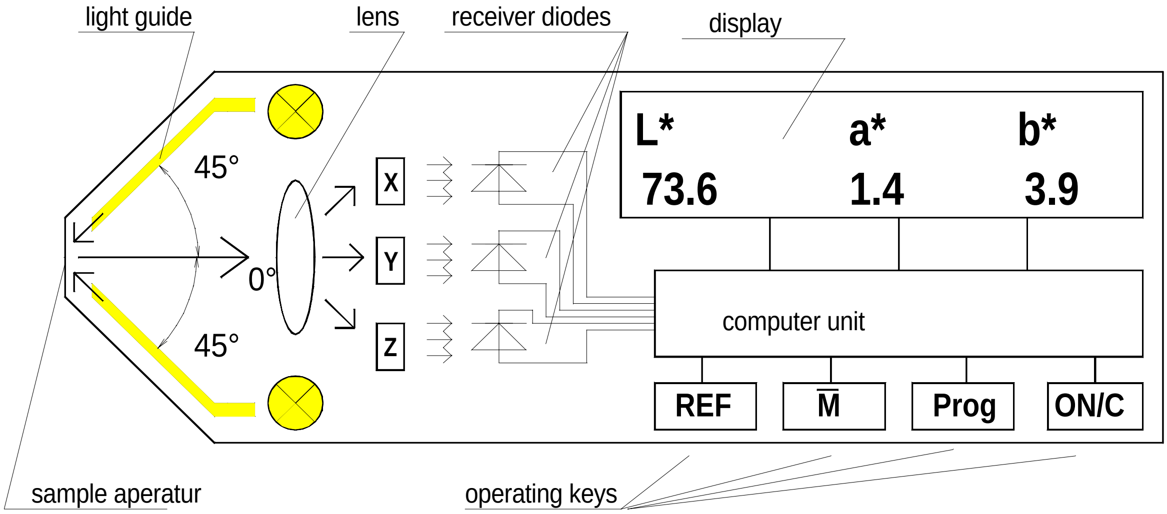


Figure 8: Principle of a 3-filter colour difference measuring instrument

Spectral method
The spectral method consists of a spectrophotometric and a colorimetric part. In the spectrophotometric part, the reflectance curve (fig. 10) of the sample is measured with a measuring head. The light which the measuring head receives is split up into its spectral shares by a diffraction grating (fig. 9).

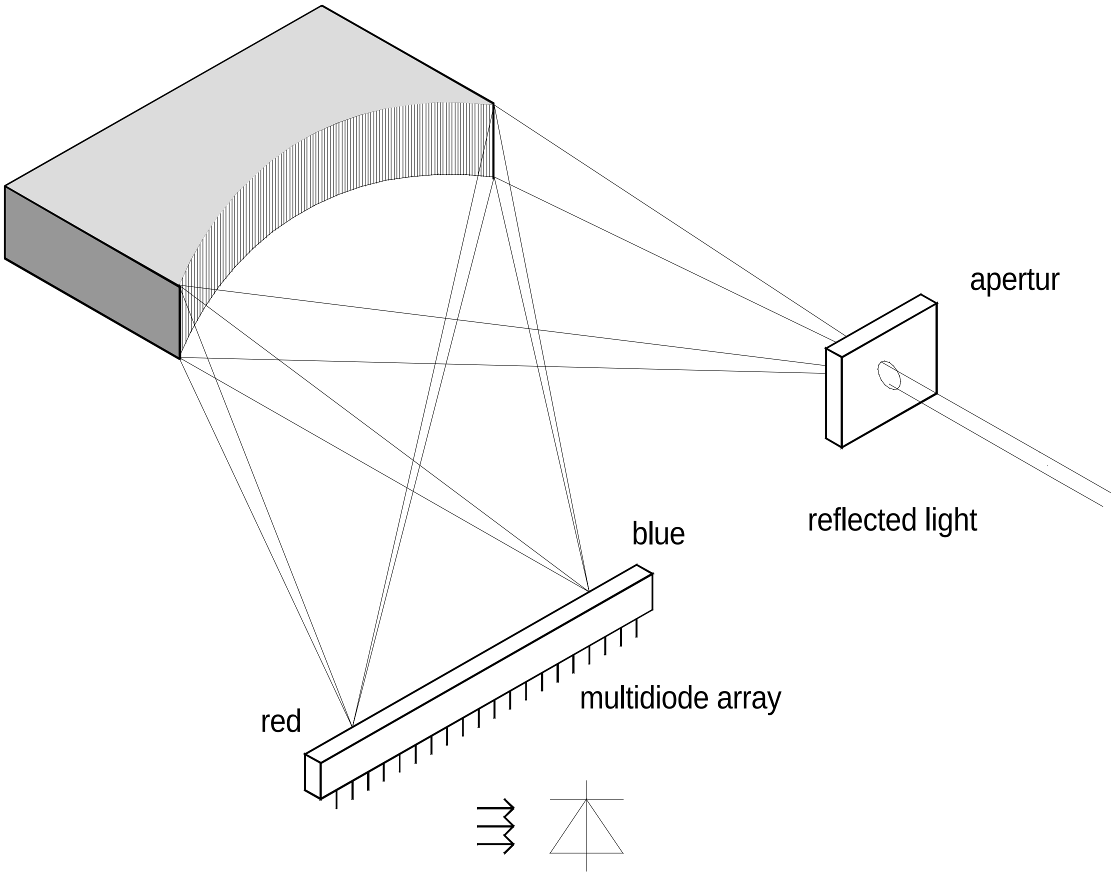


Figure 9: Diffraction grating

Depending on the resolution of the optical system, the sample reflectance ß(λ) is measured at intervals of 10nm or 20nm. The standard tristimulus values X, Y and Z are calculated from standard illuminant S (λ), standard spectral functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ or $\bar{z}(\lambda)$ and the measured reflectances ß(λ) by equations (4) to (6) see DIN 5033, part 4).

$$X = k * \int_{\lambda=380}^{720} S(\lambda) * \bar{x}(\lambda) * \beta(\lambda) * d\lambda \qquad \textbf{(1)}$$

$$Y = k * \int_{\lambda=380}^{720} S(\lambda) * \bar{y}(\lambda) * \beta(\lambda) * d\lambda \qquad \textbf{(2)}$$

$$Z = k * \int_{\lambda=380}^{720} S(\lambda) * \bar{z}(\lambda) * \beta(\lambda) * d\lambda \qquad \textbf{(3)}$$

Factor k (equation (7)) is used to standardize tristimulus value Y for ideal white. Therefore, tristimulus value Yn is always 100 for all combinations of standard illuminants and observers.

Standard tristimulus values *X, Y* and *Z* are the basis of colorimetry. As they do not give any direct information on e.g. lightness, shade or saturation of a sample, they are transposed in other colour systems.

$$k = \frac{100}{\int_{\lambda=380}^{720} S(\lambda) * \bar{y}(\lambda) * d\lambda} \qquad \textbf{(4)}$$

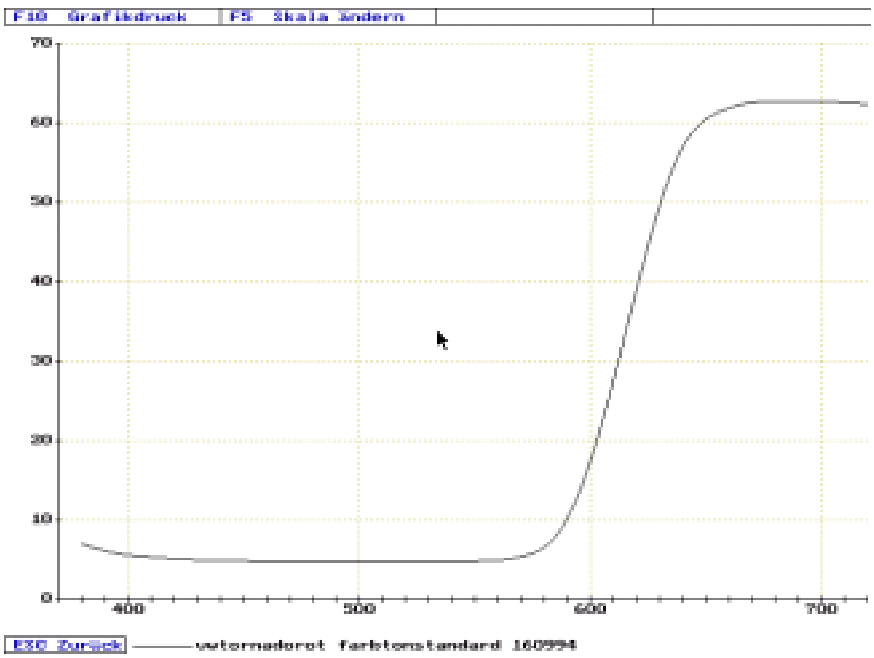


Figure 10: Reflectance curve of a red sample

Metameric Index
The metameric index describes the colour difference occurring when two samples are viewed under different illuminants. This means two samples may match perfectly under e.g. illuminant D65, but show a distinct difference under illuminant A. Such samples are called metameric pair. The metameric index is, apart from the determined colour distance between two samples, another characteristic to judge the match. The smaller the metameric index, the better samples match.

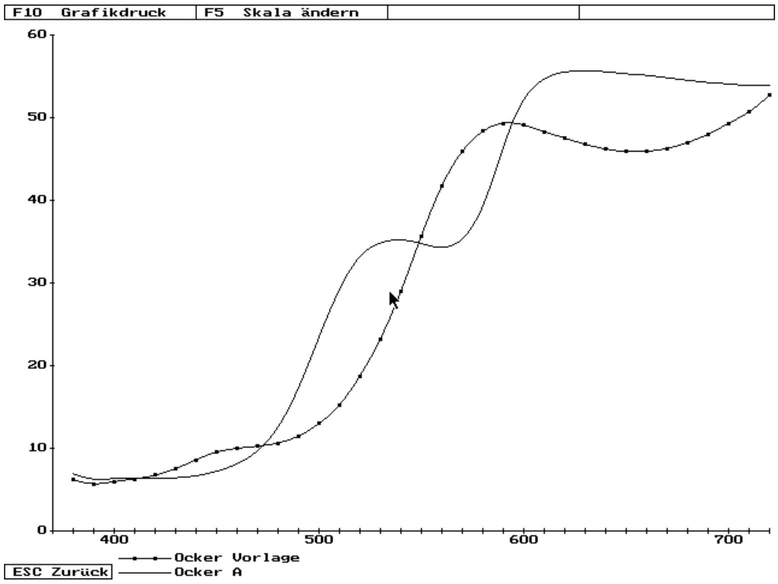


Figure 11: Reflectance curves of a metameric pair

Viewing geometries
The viewing geometry is the geometric set-up of a colorimeter. It describes the angle at which the sample is illuminated and that of the observer, i.e. how the light reflected by the sample is received in the optical part. DIN 5033 stipulates two viewing geometries to measure body colours.

Viewing geometry 45°/0°
In this mode, the sample is illuminated at an angle of 45° toward the normal line of the sample. Instruments are available with illumination from one or two sides to 45° circular illumination.

For structured samples, circular illumination is recommended, because the structure might provoke shadows under illumination from just one or two sides, leading to misjudgement. The reflected light is observed at 0°, i.e. in vertical position to the sample surface. High-gloss surfaces are measured with the specular component (gloss) excluded.

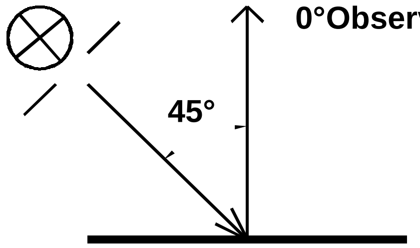


Figure 12: Viewing geometry 45°/0°

Viewing geometry d/8°
In this mode, the sample is illuminated by using an integrating sphere. The viewing position is 8° opposite the normal line of the sample. This mode includes the specular component.

These viewing geometries can be exchanged and still give the same results.

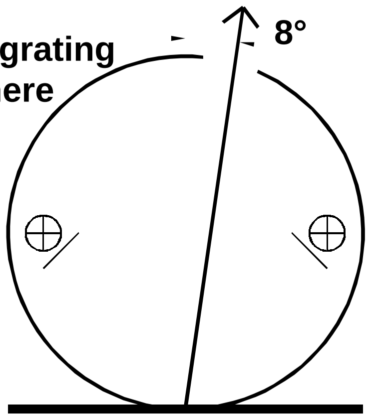


Figure 13: Viewing geometry d/8°

Colorimetry and standard colour systems
The colorimeter measures the reflectances R_{380} to R_{720} (spectral method) or reflectances Rx, Ry and Ry (tristimulus or filter method). Only when these values are known, actual colour measurement begins. The standard tristimulus values X, Y and Z are calculated by the a.m. equations and examples. They are the basis of colorimetry. Just like theoretic geometry describes the relation of a point in a three-dimensional Cartesian space, colorimetry describes a colour's position in the colour space of real colours. As the standard tristimulus values X, Y and Z do not give any direct information on lightness, shade or saturation of the sample, they are displayed as graphs and transposed into other (rectangular) colour systems. In the course of time, several theories on human colour perception have been introduced and dozens of colour systems have been developed, but in this brochure we will just present the ones used in practice. DIN 5033 part 3 defines the tristimulus system and CIE 1976 the L*a*b*-colour space.

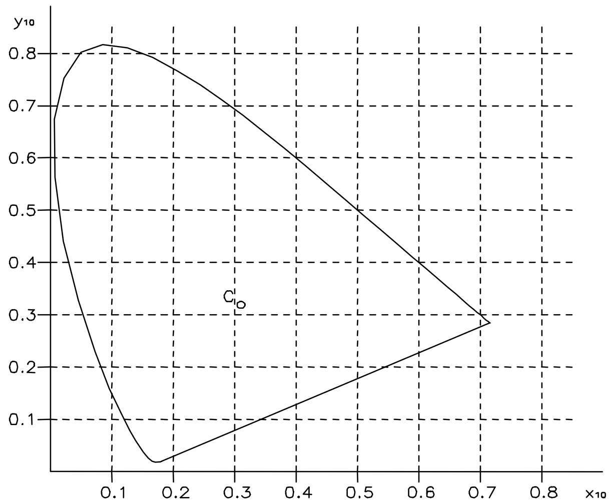


Figure 14: Colour chart of the tristimulus system

The chromaticity coordinates x and y (that is: small x and small y) in the tristimulus system are calculated by the tristimulus values X, Y and Z by the following equation:

$$x = \frac{X}{X + Y + Z} \quad \textbf{(8)} \qquad\qquad y = \frac{Y}{X + Y + Z} \quad \textbf{(9)}$$

If you mark the chromaticity coordinates *x* and *y* for all real spectral colours in a diagram, you receive a curve (horseshoe-shaped) connecting the colour locations of all spectral colours (Fig. 14). In the colour plane, only colours of equal lightness can be displayed. Colours of different lightness are located in different levels of the colour chart. In practice, however, colour appearances of different lightnesses are marked in a level of the colour chart and assigned a numerical lightness value. For graphic display, it would be necessary to show lightness, shade and saturation in a three-dimensional representation.

In principle, the standard observer employed for measurement and calculation must be taken into account in the graphic representation of colours, because the graph and spectrum locus of the light source differ for 2° and 10° standard observers.

L*a*b*-Colour space

A clearer representation than the tristimulus system is the L*a*b*-colour space (Fig. 15). The L*a*b*-system (DIN 6174 (2), among others) is a colour system correlated with subjective colour perception. The major advantage of the CIE-L*a*b*-system is the numerically equal colour difference ΔL*, Δa*, Δb* between two colours e.g. the difference between a green sample pair will be perceived the same as for a blue sample pair of identical difference value.

The L*-axis indicates the lightness of a colour, the a*-axis the red-green share and the b*-axis the yellow-blue share. The L*-values are always positive, with 0 for ideal black and 100 for ideal white colours. Red shades have positive a*-values, green shades negative ones. Yellow shades have positive b*-values, blue shades negative ones. Colour positions encircling the L*-axis are of uniform chroma C*, but differ in hue h. Colour positions on a radius beam emerging from the L*-axis have a uniform hue value, but increasing chroma. The angle between a radius beam and the positive a*-axis is designated hue h_{ab}, indicated in angle degrees between 0° and 360° and counted in mathematically positive sense (anticlockwise).

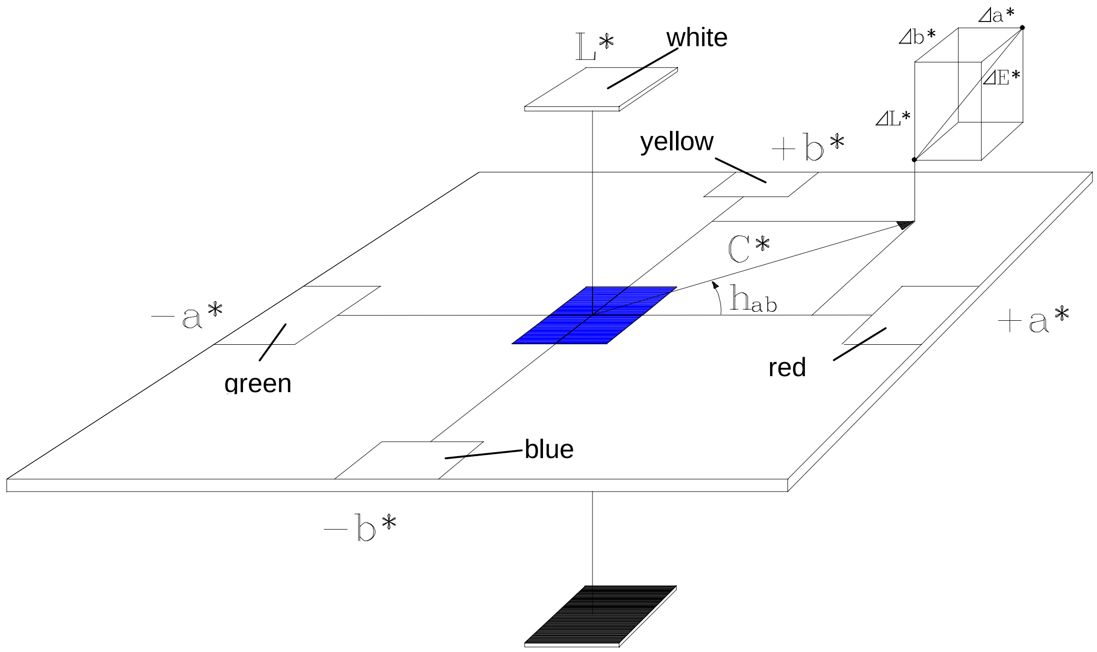


Figure 15: CIE-L*a*b*-system according to DIN 6174

The L*,a*,b*-b*-values are calculated from the standard tristimulus values with equations (10) to (14) and are, therefore, also dependent of standard illuminant (A, C or D65) and observer (2° or 10°).

$$L^* = 116 \bullet \sqrt[3]{\frac{Y}{Y_n}} - 16 \qquad \textbf{(10)}$$

$$a^* = 500 \bullet \left\{ \sqrt[3]{\frac{X}{X_n}} - \sqrt{\frac{Y}{Y_n}} \right\} \qquad \textbf{(11)}$$

$$b^* = 200 \bullet \left\{ \sqrt[3]{\frac{Y}{Y_n}} - \sqrt[3]{\frac{Z}{Z_n}} \right\} \qquad \textbf{(12)}$$

$$C^* = \sqrt{a^{*2} + b^{*2}} \qquad \textbf{(13)}$$

$$h_{ab}^* = \arctan \frac{b^*}{a^*} \qquad \textbf{(14)}$$

	2° - standard observer			10° - standard observer		
	illuminant					
	D65	C	A	D65	C	A
X_n	95,05	98,07	109,85	94,81	97,28	111,14
Y_n	100,00	100,00	100,00	100,00	100,00	100,00
Z_n	108,90	118,22	35,58	107,34	116,14	35,20

Colour difference ΔE*

According to DIN 6174, the colour difference ΔE* between two colours is calculated from the differences of their respective L*, a*, b*-values.

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad \textbf{(15)}$$

with

$$\Delta L^* = L_P^* - L_B^* \qquad \textbf{(16)}$$

$$\Delta a^* = a_P^* - a_B^* \qquad \textbf{(17)}$$

$$\Delta b^* = b_P^* - b_P^* \qquad \textbf{(18)}$$

For achromatic colours or slightly tinted shades of grey, the separation into portions of ΔL*, Δa* and Δb* indicates immediately the direction of the actual colour difference, i.e.:

Δ L*	positive	sample lighter than reference
	negative	sample darker than reference
Δa*	positive	sample redder than reference
	negative	sample greener than reference
Δb*	positive	sample yellower than reference
	negative	sample bluer than reference

The following figure shows a geometric representation of the differences between the individual components and is used in DIN 55981 and ISO 787 -25 for almost achromatic colours.

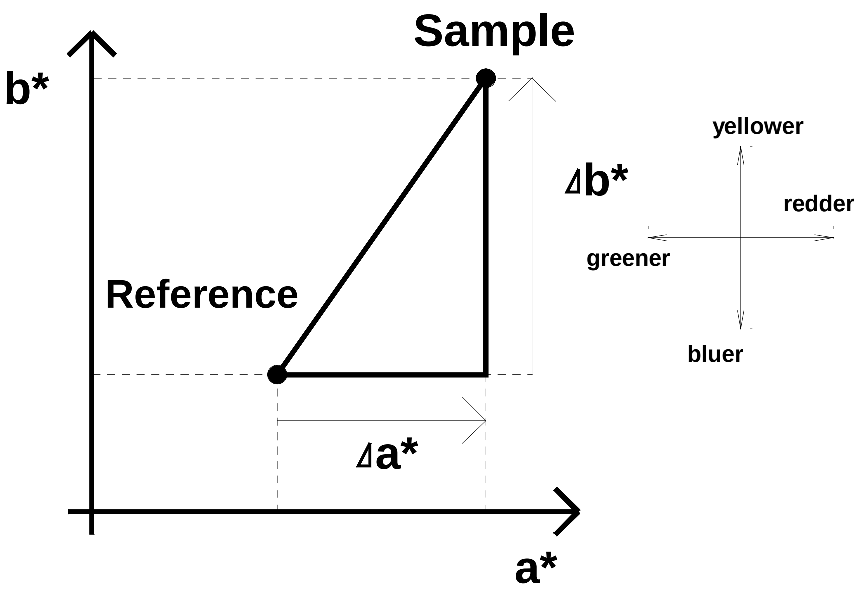


Figure 16: Colour difference ΔE* split up into Δa* and Δb*

For chromatic colours, DIN 6174 defines a splitting-up of the overall colour difference ΔE* by its portions of lightness, chroma and hue.

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta C^*_{ab})^2 + (\Delta H^*_{ab})^2} \qquad \textbf{(19)}$$

$$\Delta C^*_{ab} = C^*_{ab,P} - C^*_{ab,B} = \sqrt{a^{*2}_P + b^{*2}_B} - \sqrt{a^{*2}_B + b^{*2}_P} \qquad \textbf{(20)}$$

$$\Delta H^*_{ab} = s \bullet \sqrt{\left(\Delta E^*_{ab}\right)^2 - \left(\Delta L^*\right)^2 - \left(\Delta C^*_{ab}\right)^2} \quad \textbf{(21)}$$

where s=-1, if $a^*_P\ b^*_B > a^*_B\ b^*_P$ and s = 1.

Where ΔC^*_{ab} = chroma portion or difference in saturation
and ΔH^*_{ab} = hue portion or difference in shade.

ΔC^*_{ab} positive — sample clearer, more brilliant than reference
negative — sample duller, more turbid than reference

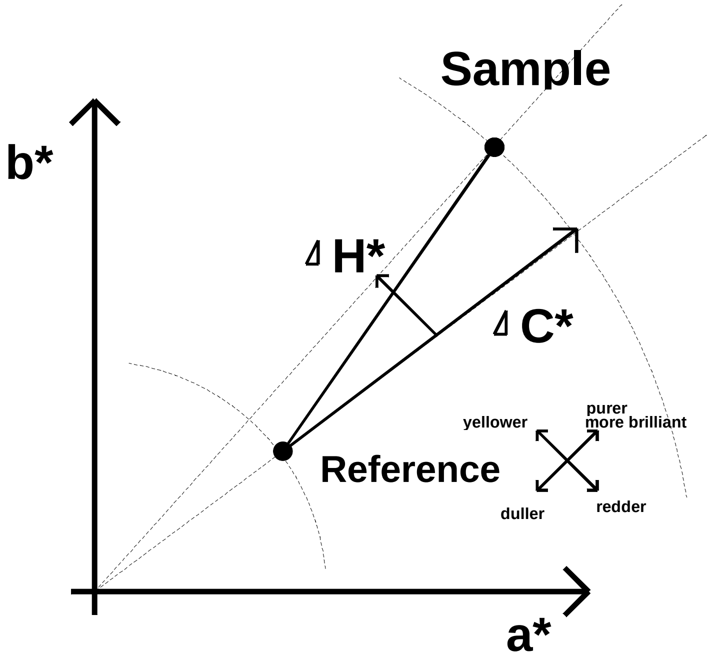


Figure 17: Colour difference ΔE^* split-up into ΔC^*_{ab} and ΔH^*_{ab}

Modified colour difference ΔE^*_{94}

Practical industrial application has revealed that acceptable and unacceptable ΔE^* colour differences give an identical numerical value, e.g. $\Delta E^*_{ab} = 1$. In case of very saturated hues, for instance, $\Delta E^*_{ab} = 1$ is more readily accepted than for achromatic or pastel hues. The same is true for brilliant colours where tolerances of chroma deviation (saturation) ΔC^*_{ab} are much larger than those accepted for hue deviations ΔH^*_{ab}. In practice, an ideal colour difference formula should include a uniform tolerance value ΔE^*. That is why modifications to the CIE-L*a*b*-formula were elaborated, taking the dependence of colour and direction of the colour difference into account.

CIE recommends to use the ΔE^*_{94} colour difference formula. In this formula, the components ΔC^*_{ab}, ΔH^*_{ab} and ΔL^* of the CIE-L*a*b*-formula are modified with additional factors.

$$\Delta E^*_{94} = \sqrt{\left(\frac{\Delta L^*}{S_L k_L}\right)^2 + \left(\frac{\Delta C^*_{ab}}{S_C k_C}\right)^2 + \left(\frac{\Delta H^*_{ab}}{S_H k_H}\right)^2} \qquad \textbf{(22)}$$

where S =	Constant values for balanced weighting of internal irregularities in the CIELAB-formula
k =	constant values for balanced weighting if viewing depends on external parameters influencing the perception of colour differences.

A comprehensive evaluation determines:

$S_L = 1$
$S_C = 1+0.045\ C^*_{ab}$
$S_H = 1+0.015\ C^*_{ab}$

where C^*_{ab} = reference or geometric mean value of reference and sample

$$\sqrt{C^*_{ab,B}\ C^*_{ab,P}}$$

This formula applies to standard viewing conditions:

$k_L = k_C = k_H = 1$
For applications in the textile industry, this formula is recommended:

$k_L = 2$ and $k_C = k_H = 1$

Special sectors of colorimetry
Some sectors of industry produce mainly white products. For various applications with paper, textiles, chemicals etc., formulas were set up to determine the degree of whiteness and express it in a number to describe the whiteness of the products. The common formulas for the degree of whiteness are:

Degree of whiteness by Berger
$W_B = R_Y + 3(R_Z - R_X)$ **(23)**

Whiteness index
WI = 3*(1.242 Z - Y) **(24)**

Yellowness index
To describe the yellowing of a white product, the yellow value (DIN 6167) or yellowness index (ASTM D 1925) is calculated as follows:

$$G = \frac{a \bullet X - b \bullet Z}{Y} \quad \textbf{(25)}$$

Factors a,b are indicated in the following table:

standard illuminant	D65	C
standard observer	10°	2°
a	1,301	1,277
b	1,149	1,059

Opacity and transparency
Reflection measurements can also describe the transparency of an object, e.g. paper. In this case, the important factor is reflectance R, which is the basic value of all measurements made at paper and cardboard. DIN 53145 defines the requisites to determine the reflectance.

Opacity is a measure for the transparency of a paper (DIN 53146). It is the ratio between reflectance R_0 and reflectivity R_∞ .

$$O = \frac{R_0}{R_\infty} \quad \textbf{(26)}$$

Where:

R_0 reflectance of a sample sheet over perfect black

R_∞ reflectivity of the same sample on a pile of identical sheets which is so thick that it is opaque.

Transparency T in terms of percentages is a measure of the transparency of a paper (DIN 53147). It is calculated with the reflectance determined according to DIN 53145 as follows:

$$T = \sqrt{(R_W - R_0)\left[\frac{10000}{R_{(W)}} - R_0\right]} \quad \textbf{(27)}$$

Where:

R_0 reflectance in % of a single sheet over perfect black

R_W reflectance in % of a single sheet over perfect white

$R_{(W)}$ reflectance in % of white backing

The CMC Equation (BS 6923)

Since 1976 the CIELAB formula is used internationally for quantifiying the colour difference between surface colours.

During the last year over 50.000 assessments made by 44 professional shade passers in the textile and paint industries against reference specimens of 262 different colours were analysed. It was found that if the decisions had been made using the optimum CIELAB ΔE* value of the pass/fail boundary for each of the four data sets the number of wrong decisions would have been significantly greater than the average number of wrong decisions made by the assessors.

The ideas and reasoning behind the modifications made to the JPC79 colour difference formula in developing it into the CMC equation are given by F.J.J. Clarke, R. McDonald and B. Rigg in ”Modification to the JPC79 colour difference formula”, Journal of the Society of Dyers and Colourists, 1984, 100, 128-132 and 281-282. Applying CMC (2:1) to the four data sets already mentioned gives fewer wrong decisions than would be made by the average observer, and in the only data set giving individual assessments (8 observers), the number of wrong decisions was no greater that that made by the most reliable assessor.

The relative importance of lightness and chroma differences compared with differences in hue varies in different industries, and to allow for this, relative tolerances for I and c are included in the formula.

Currently, optimum values of I and c have only been determined for the textile industry. However, work is proceeding on determining optimum values for I and c for other industries, e.g. ceramics, leather, paper, paint and plastics, which will lead to revisions of this standard.

Calculate the colour differences in CMC (I:c) units using the following equation:

$$DE = \left[\left(\frac{\Delta L^*}{IS_L}\right)^2 + \left(\frac{\Delta C_{ab}{}^*}{cS_C}\right)^2 + \left(\frac{\Delta H_{ab}{}^*}{S_H}\right)^2\right]^{0.5}$$

Note. When I = c = 1 the formula quantifies the perceptibility of colour differences. Optimum values of I and c for quantifying the accespability of a colour match have so far only been determined for the textile industry, and these values are I = 2 and c = 1.

For more details please refer to the BS 6923.

Literature and standards

DIN 5033	Colorimetry Parts 1-8.
DIN 6172	special metamerism-index for pairs of samples at change in illuminant
DIN 6174	Colorimetric evaluation of colour differences of surface colours according to the CIELAB formula.
DIN 53146	Testing of paper and board; determination of opacity
DIN 53147	Testing of paper; determination of transparency
DIN 53236	Prüfung von Farbmitteln; Mess und Auswertebedingungen zur Bestimmung von Farbunterschieden bei Anstrichen, ähnlichen Beschichtungen und Kunststoffen
DIN 6167	Description of the Yellowing of Near White or Colourless Materials
ASTM 1925	Test for Yellowness Index of Plastics
DIN 53162	Hiding-Power Determination of Air-Drying Achromatic Paints
DIN 53234	Determination of Relative Intensity in White Brightenings
ASTM D 2244	Instrumental Evaluation of Color Differences of Opaque Materials
ASTM D 2805	Test for Hiding Power of Paints
ASTM E 97	Test for 45-deg Directionalo Reflectance of Opaque Specimens by Filter Photometry
ASTM E 313	Test for Indexes of Whiteness and Yellowness of Near-White Opaque Materials
NF X 08-012	Methodes et appareils de mesures des caracteristiques Colorimetriques
DIN 6175	Colour Tolerances in Car Coatings
BS 6923	Calculation of small colour differences
ASTM E 308-85	Computing the Color of Objects by using the CIE-System
Loos, H.	Farbmessung, Verlag Beruf + Schule 1989.
Möller-Kemsa, J.	Farbmessung an transparenten Flüssigkeiten, SÖFW Nr. 15/1991.
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Völz ,H.	Industrieelle Farbmessung; VCH Verlagsgesellschaft
Billmeyer Jr. F.W.	
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All standards can be obtained through all International Standards Organisations.