Objective color assessment and quality control in the chemical, pharmaceutical and cosmetic industries

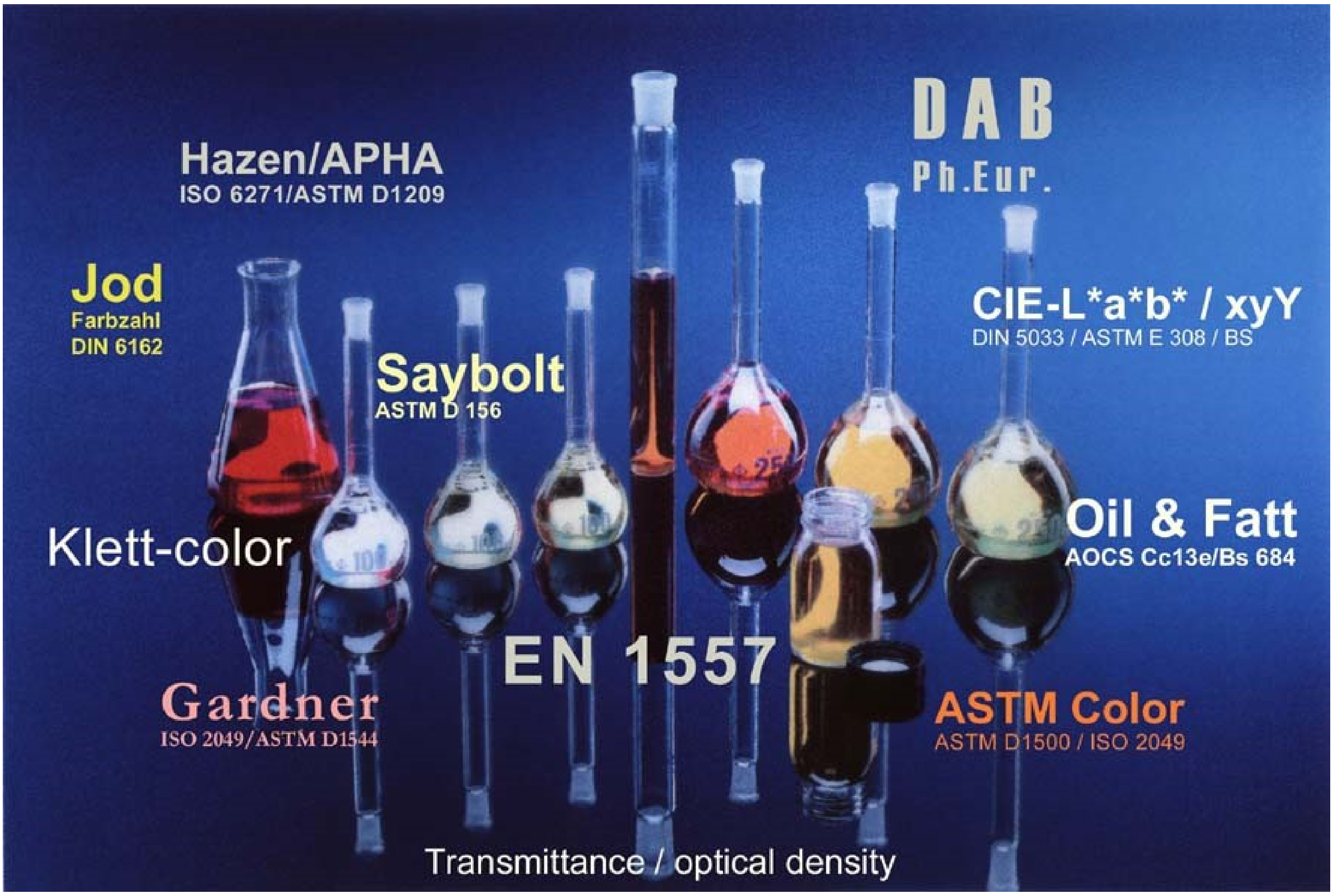

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TABLE OF CONTENT

A From visual color assessment to objective color measurement

Exacting quality standards and the companies' interest in certifications paved the way for color measurements in the chemical, pharmaceutical and cosmetic industries. Therefore, suitable measuring procedures must provide objective and traceable production data for documentation which will prove e.g. in case of customer's complaints that given tolerances have been met. Ever constant product characteristics evidence good quality in the opinion of clients and users. Such constancy, however, cannot be maintained by purely subjective assessment in view of nowadays high demands on product quality.

Many different color systems have been developed for visual color assessment since Sir Isaac Newton introduced his book "*Opticks*" the beginning of the 18th century. Aristotle already studied the subject of light and colors. He described experiments in optics using a camera obscura in Problems, book 15. The apparatus consisted of a dark chamber with a small aperture that let light in. With it, he saw that whatever shape he made the hole, the sun's image always remained circular. He also noted that increasing the distance between the aperture and the image surface magnified the image. In 1801 Thomas Young proposed his trichromatic theory, based on the observation that any color could be matched with a combination of three types of light sources (RGB). The principles of Newton's law of mixture were experimentally confirmed by Maxwell in 1856. This theory was later refined by James Clerk Maxwell and Hermann von Helmholtz. Helmholtz's "Manual of Physiological Optics," published in 1867, forms the basis of today's instrumental colorimetry.

A1 The term "color"

Every object has individual material qualities or characteristics, for instance volume, extension or density. Color assessment focusses on the optical characteristics of the material, i.e. its ability to modify incident light waves. If an object is exposed to light, it reflects a certain portion of the light, absorbs another portion and transmits the rest. According to DIN 5036, the relations of these portions to the entire amount of incident light are identified by reflectance ß (reflected portion), transmittance τ (transmitted portion) and absorptions α (absorbed portion), with this equation valid for all media:

$$\beta + \alpha + \tau = 1 \qquad \textbf{(1)}$$

The reflectance ß is the used for color measurement of solid, opaque materials (surfaces). The transmittance τ is used for color measurement of optical clear, transparent materials (clear liquids, foils). The absorptions α of a material cannot be measured directly but calculated by using formula 1.

The term "color" has many different meanings. It is used for the paint which a painter applies to a canvas. It is also used for a characteristic of an object the eye perceives. In the sense of standardisation, "color" is a sensual perception the human eye transmits to the brain. ISO 11664 defines:

"*Color is the sensation of a part of the visual field which the eye perceives as having no structure and by which this part can be distinguished alone from another structure less and adjoining region when viewed with just one motionless eye*".

Color perception is, like any other spatial perception, three-dimensional. This means that colors can be described by three clear measures of quantity like e.g. lightness, hue and saturation, unless verbal descriptions (pink, sky-blue, ocean-blue, grass-green, etc.) or, if suitable standards are available, comparative statements like e.g. RAL 9001 or Iodine number 5 are considered satisfactory.

A2 Visual Color Scales

Most of the common visual color systems to assess the colors of transparent liquids were elaborated at the end of the 19th century and beginning of the 20th century. At that time, these color systems were defined as the first means to match product colors with reproducible standard solutions. The parent standard solutions were made from potassium-palatinate, iodine or ferric chloride and were then diluted to smaller color gradations. The most common ones beside Iodine, Hazen and Gardner color values are e.g. the Saybolt-color number, the mineral oil color according to ISO 2049 and ASTM D-1500, the Klett-color number in the cosmetic industry, the FAC[1]-scale, the EBC-scale and the pharmacopoeia-color scale according to the US-, European, Japanese or Chinese pharmacopoeia´s. Moreover, there are many other color systems in use like, e.g. Shellac-, Woma[2]-, ICUMSA-, Dichromate-, Barratt-, AcidWash-, or Red-Dye color.

A2.1 The Hazen (PtCo) Color Number

The Hazen color number (ISO 6271, also known as ″APHA[3]-method″ or platinum-cobalt-scale) is defined as mg of platinum per ml solution. To prepare the Hazen parent solution (color number 500), 1.246g of potassium-hexachloroplatinate (IV) and 1.00 g of cobaltous chloride are dissolved in 100ml of hydrochloric acid and filled-up with distilled water to make 1000ml. The Hazen color scale is suitable for almost water-clear products. The steps in the light brownish-yellowish range are closer than in the Iodine and Gardner color scale, reaching water-clear tints. The newest edition of ISO 6271:2015-12 describes and defined only the instrumental color measurement with a spectrophotometer. The part of visual color determination is now completely removed.

A2.2 The Gardner Color Number

The Gardner color number is defined in ISO 4630. The method is applicable for drying oils, varnishes and solutions of fatty acids, polymerized fatty acids, resins, tall oil, tall oil fatty acids, rosin and related products. For other products, the results can be wrong. The usability of this color scale should then be checked. The light-yellow Gardner color numbers (1 to 8) are based on potassium chloroplatinate solutions, color numbers 9 to 18 on solutions of ferric chloride, cobaltous chloride and hydrochloric acid. A considerable drawback of the Gardner scale is the relatively great distance between color values 8 and 9. The most recent edition of ISO 4630:2015-12 describes and defined the instrumental color measurement with the use of a spectrophotometer only. The part of visual color determination is now removed. The method according to ISO 6271 is recommended for products with a bright color than Gardner color 1.

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1 AOCS Cc 13a-43, FAC Standard Color
2 White Oil Manufact. Association IP17
3 American Public Health Association

A2.3 The Iodine Color Number

DIN 6162 defines the Iodine color number as mg of iodine per 100ml potassium iodide solution. Color matching with the Iodine number serves to assess the color depth of clear liquids like e.g. solvents, plasticizers, resins, oils and fatty acids with colors similar to that of the iodine-potassium-iodide solution at the same path length. For Iodine values around 1 or smaller, it is recommended to use the Hazen color number according to ISO 6271. DIN 6162 rules that the iodine color reference solutions be verified at least once a year by comparison with fresh solutions. As this method is a subjective one, the DIN gives no details regarding reproducibility and repeatability. Moreover the DIN reads: ″In case of major differences between the sample color and that of the Iodine color scale this method should not be employed″. The most recent edition of DIN 6162:2014-09 removed the visual color determination section and aligned the text and wording to the actual ISO 4630 and ISO 6271.

A2.4 The Lovibond®-Color System

Color assessment with the Lovibond®[4]-color system is deeply rooted in the fat and oil industries. The Lovibond®-system can be traced to an English beer brewer who lived in the 19th century: in 1885, he conceived this color evaluation system to judge his mash. The system was updated with either visual-mechanical or photometric methods of measuring. But visual systems tend to be influenced by subjective factors, and photometric instruments show more or less considerable measuring differences when results are compared directly. Strictly speaking, the employed instrument and the path length of the cuvettes (usually 5¼ inch (13.34cm) or 1 inch (2.54cm)) should be specified with the Lovibond®-value. The determination of color values by LICO 690 is in compliance with the AOCS[5] Cc 13e and BS 684-1.14 - methods[13]. The excellent accuracy provided by LICO 690 - instrument permits even the use of the 11mm round glass cuvette to measure very small Lovibond®-values. Moreover, the old LICO 200 provided a correction factor to be entered for yellow and red values (Ly and Lr). By modifying these factors, the Lovibond®-values measured with LICO 200 could be adjusted to present old Lovibond-instruments. ISO 27608:2010 Animal and vegetable fats and oils - Determination of Lovibond color - Automatic method. This International Standard specifies a method for the determination of Lovibond® color of animal and vegetable fats and oils using automatic instrumentation.

A2.5 The Saybolt- and Mineral Oil Color Numbers

The Saybolt-scale (ASTM[6] D156) is employed to match water-clear, colorless to slightly yellowish colored products (e.g. pharmaceutical white oils, paraffins and mineral oils). The color gradation of the Saybolt-scale is similar to that of the Hazen-scale (APHA) and is therefore employed for the measurement of water-clear, slightly yellowish products. The faintest coloration is Saybolt-color number +30 (corresponding to about 8-9 Hazen), the strongest evaluable Saybolt-coloration value is -16. A Saybolt-color value of 0 corresponds to about 160 Hazen.

The mineral oil color number (ASTM D1500) is employed to assess the colors of strongly colored oils and waxes. Color numbers 0 to 8 are similar in tint, hue and chroma to the Gardner color scale. ASTM D1500 does not define liquid standards but is based on visual color comparison and the color data of ancient color disks. Thus, no liquid color standards can actually be applied according to ASTM

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[4] Lovibond® is a registered trademark of THE Tintometer® LTD, UK

[5] American Oil Chemists´ Society

[6] American Society for Testing and Materials

D1500. A more recently published ASTM D6045 defines fluid standards that are said to be usable for the D1500. ASTM D6045 in turn has a correlation to ASTM D1500 of only R=0.48. However, the reproducibility in D6045 is only given for different assessors in different laboratories. A difference or correlation between devices of different manufacturers is not mentioned. ASTM D6045 standards are costly to produce and the given calculations, accuracies and tolerances are very difficult to follow.

A2.6 The European Pharmacopoeia 2.2.2 - Color Number Determination

In the American pharmacopoeia USP, chapter <1061> 'Color-Instrumental Measurement', color measurement according to the CIE-Lab*-colorimetric system (ASTM Z 58.7.1 and ISO 11664) was defined many years ago. In Europe, however, tests and acceptances in the pharmaceutical industry are performed by visual color matching on the basis of the European Pharmacopoeia (EP or PharmEur) but with the LICO instruments also the instrumental measurement of the EP colors became true in 1994. With the release of the EP edition 10.3 beginning of 2021 a new method III for instrumental measurement of the color in liquid samples was deployed. The preparing of the color reference solutions as described in the EP is rather laborious and requires utmost care. From three parent stock solutions for red (cobaltous (II) chloride), yellow (ferrous (III) chloride) and blue colors (cuprous (II) sulphate) and 1% hydrochloric acid, five color reference solutions for Yellow (Y), Greenish-Yellow (GY), Brownish-Yellow (BY), Brown (B) and Red (R) hues are prepared. With these five reference solutions in turn, a total number of 37 color reference solutions is prepared (Y1-Y7, GY1-GY7, BY1-BY7, B1-B9 and R1-R7). Each reference solution is clearly defined in the CIE-Lab color space e.g. by lightness, hue and chroma.

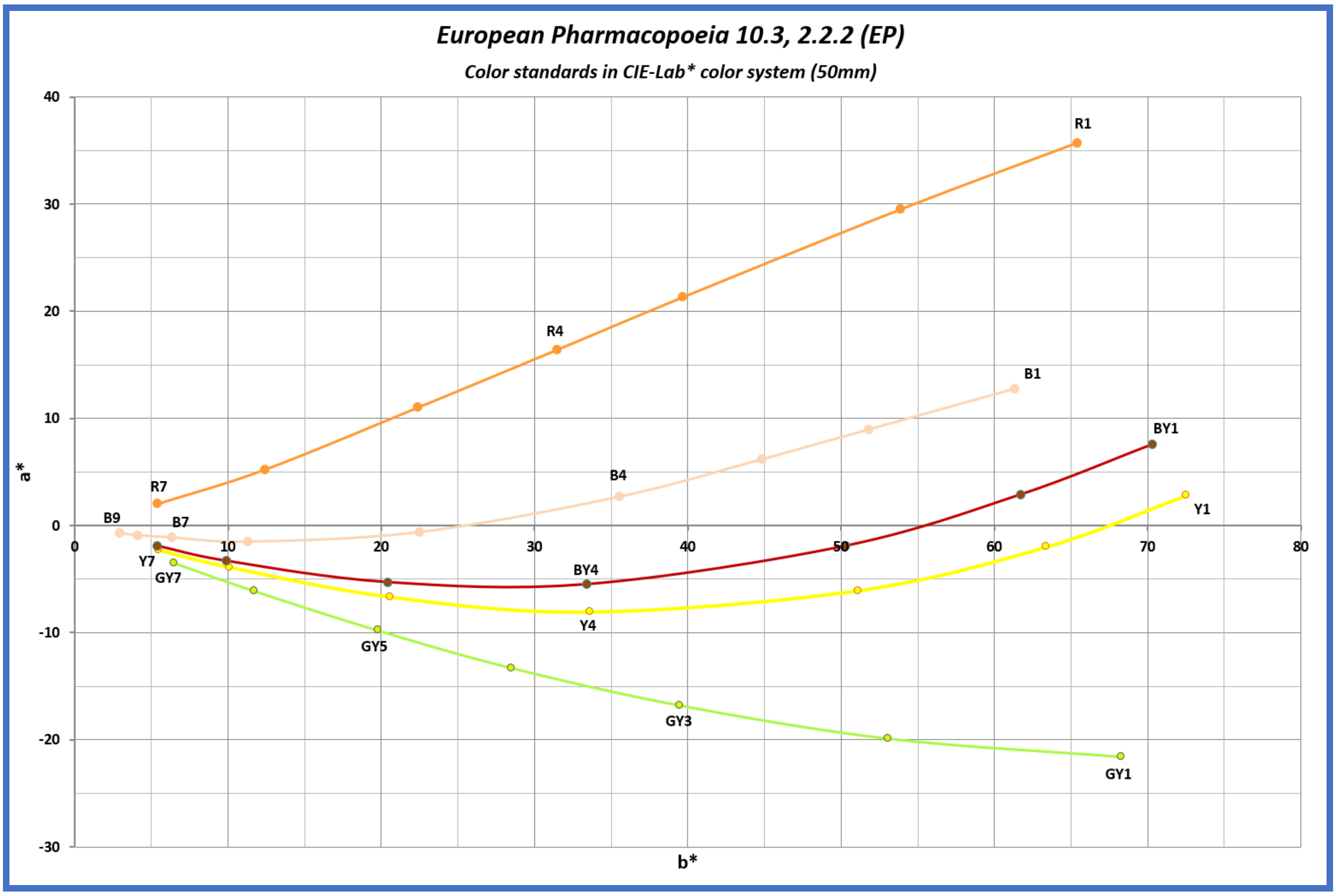


Fig. 1 European Pharmacopeia color reference solutions in the CIE-Lab-system

The CIE-Lab*-values of all 37 colorimetric reference solutions are stored in the LICO 690 colorimeter and used directly for the color calculation of the measured sample. A detailed instrument validation report about the pharmacopoeia color evaluation can be requested through the Hach Techsupport.

A2.7 The US Pharmacopoeia <631> - Color determination

The LICO 690 method of determining color in accordance with the U.S. Pharmacopoeia corresponds to the USP specifications in Chapter <631> "Color and Achromicity " and Chapter <1061> "Color - Instrumental measurement". A total of 20 color reference solutions (identified sequentially by the letters A to T) are defined in the U.S. Pharmacopoeia Chapter <631> and the CIE-L*a*b*-values of all these 20 reference solutions are stored in the LICO 690. The stored values are used directly for the color calculation of the measured sample liquid. The color of the measured sample is automatically correlated to the nearest color reference solutions. This means that the color reference solution that is closest to the sample (i.e. the reference solution with the smallest color difference ΔE* to the color of the sample) is displayed. The ΔL*, Δa* and Δb* values given by the instruments display or print-out give the quantitative differences between the L*, a* and b* values of the sample and those of the displayed letter of the USP solutions. The measurements can be carried out with cuvettes/sample cells with a path length of 10 mm, 11 mm or 50 mm. The use of sample cells with higher path lengths increases the accuracy associated with the measurement.

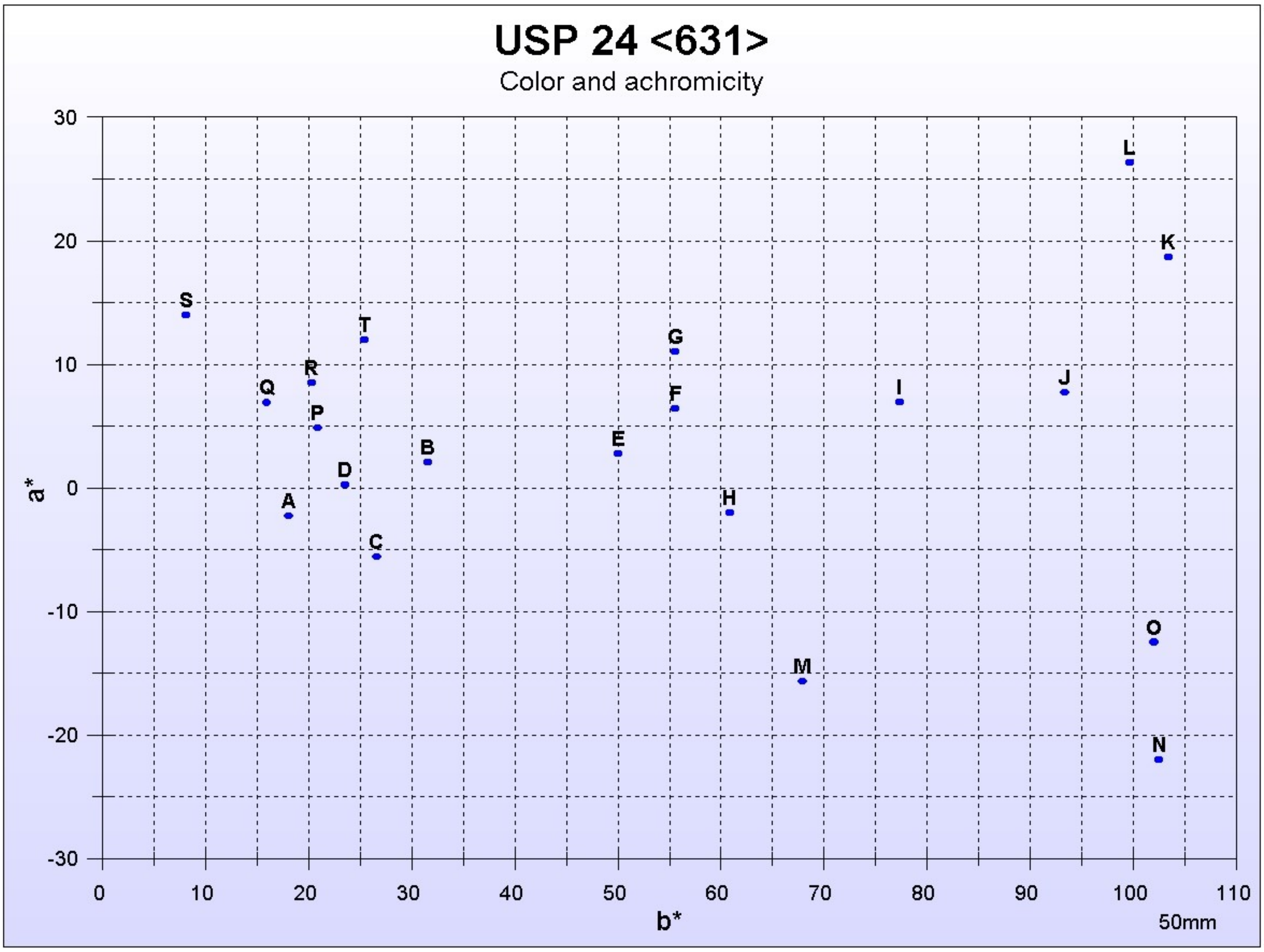


Fig. 2 Location of the USP-color solutions in the CIE-Lab-system

Method IIa: Comparative test of colors using CIE-Lab values

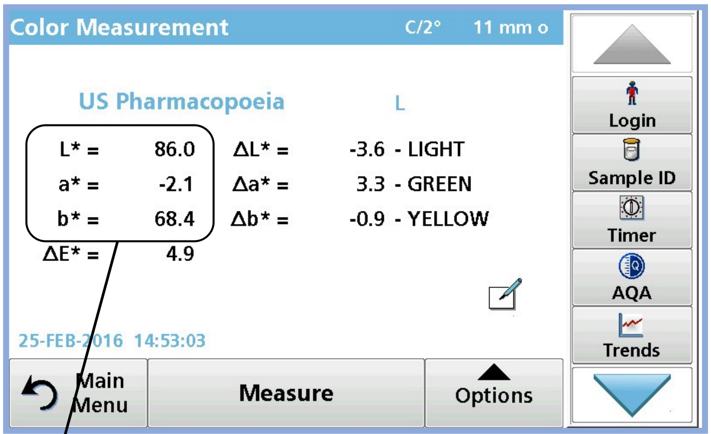
The USP <631> Method IIa defines a comparative test of colors of samples to the color values of a matching solution. The CIELab* values for a sample and a matching solution may be evaluated to determine the acceptability of the sample. Table 2 lists the different metrics that may be used for the color evaluation of a sample and describes the interpretation of the color. In evaluating stability, the color values may be tracked over time to assess trends.

Color evaluation test	***Test***	***Requirement***
Almost Colorless	Compare the sample to Purified Water.	Measure the sample and Purified Water. Calculate ΔE^* relative to Purified Water. Requirement is that $\Delta E^* < 1$.
Maximum Level of Color	Identify a matching fluid of similar hue angle ($\Delta h_{ab} < 15$) that is discernibly more colored than the sample.	Measure the matching fluid and calculate the ΔE^*r relative to Purified Water. Measure the sample and calculate the ΔE^* relative to Purified Water. Requirement is $\Delta E^* < \Delta E^*_r$.
Minimum Level of Color	Identify a matching fluid of similar hue angle ($\Delta h_{ab} < 15$) that is discernibly less colored than the sample.	Measure the matching fluid and calculate the ΔE^*r relative to Purified Water. Measure the sample and calculate the ΔE^* relative to Purified Water. Requirement is $\Delta E^* > \Delta E^*_r$.
Indiscernible from Color Standard	Prepare color standard; compare the test sample to the color standard.	Calculate ΔE^* relative to selected color standard. Requirement is that $\Delta E^* < 3$.

Table 2: Interpretation of Color Comparisons

Method IIb: Instrumental color assessment

The CIELab* values (calculated as described in Method IIa) may be used directly as a quantitative measure of the color attributes of a sample. Acceptable specifications for the color attributes can be established in the CIELab* color space and applied to color values obtained for a sample. Also, for new monographs under development, acceptable numerical limits within color space should be determined based on process capability, stability, and analytical variability. CIELab* color values are dependent on the illuminant and observer used for the color calculation and, therefore, should be reported together with the used type of sample cell path length and the calculated Lab* values of the sample.



Reporting of Results

The recommended method for reporting the CIELab* results is to report the color values as shown in the following example:

CIELab* $(C/2°)_{11mm}$ L* = 86.0, a* = -2.1, b* = 68.4

A2.8 The Chinese Pharmacopoeia – ChP 0901 Color determination

The description and definition of color determination in the Chinese Pharmacopoeia (ChP) is similar in principle to the European Pharmacopoeia Color method in that the colors are made using yellow, red and blue primary stock solutions. However, the chemical definition of the yellow solution is different to the EP and the proportion of solution used and the color designations are different.
Out of the three primary colorimetric stock solutions there are five reference stock solutions mixed with different tints:

- Brownish Red (BR)
- Orange Red (OR)
- Orange Yellow (OY)
- Yellow (Y)
- Yellowish Green (YG)

The most recent Chinese Pharmacopeia revised in 2015 added an additional dilution step 0.5 to each color scale and a definition of a 6th reference solution called:

- Greenish Yellow (GY)

Each of the reference stock solution is then diluted with water into 11 concentration standards (matching solutions). The reference solutions are prepared for each color scale using the following dilution table:

Color Number	0.5	1	2	3	4	5	6	7	8	9	10
Stock solution / ml	0.25	0.5	1.0	1.5	2.0	2.5	3.0	4.5	6.0	7.5	10.0
Dist. water / ml	9.75	9.5	9.0	8.5	8.0	7.5	7.0	5.5	4.0	2.5	0

This results in a total quantity of 66 color reference solutions! Eleven of each tint.

The CIE-Lab values of the 66 reference solutions are stored in LICO 690 for all three sample cell path lengths (10mm, 11mm and 50mm) and used for the ΔE^* color calculation.

Definition of ChP Method 3 for testing the color of a solution:

Unless otherwise specified, the color difference ΔE^*_{wp} of the sample liquid to water should not be more than the ΔE^*_{ws} difference of the reference standard solution to water:

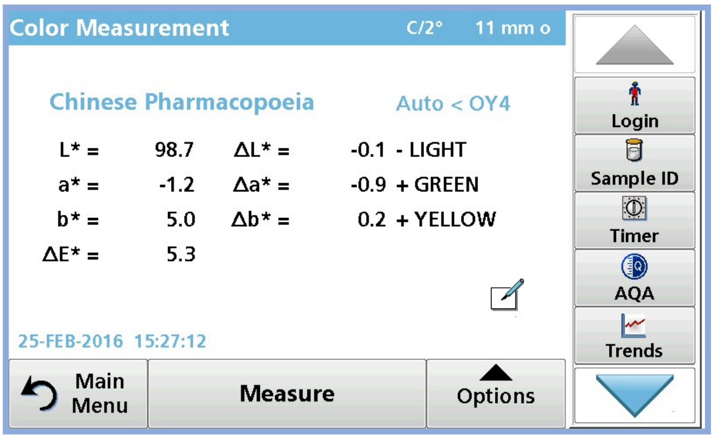
$$\Delta E^*_{wp} \leq \Delta E^*_{ws} \qquad (2)$$

with

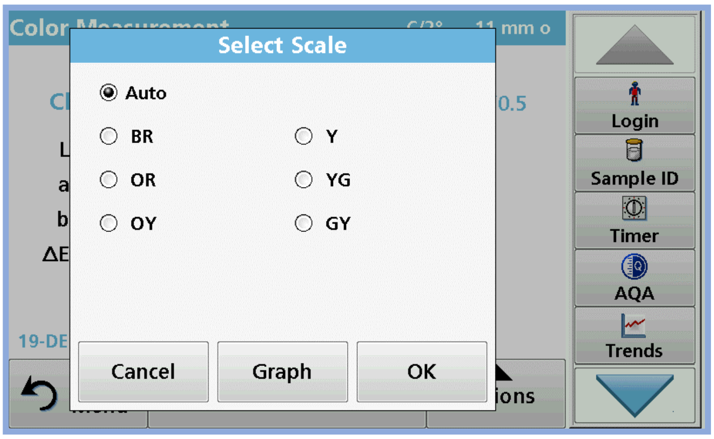
$$\Delta E^*_{wp} = ((L^*_p - 100)^2 + a^{*2}_p + b^{*2}_p)^{0,5}$$

The result of this assessment is independent from the used light source and observer settings.

The LICO 690 displays the CIE-Lab* values of the sample after the measurement. On the top right the nearest higher ChP color reference solution (here OY4) and the ΔE^*_{wp} value of the sample calculated against uncolored distilled water.

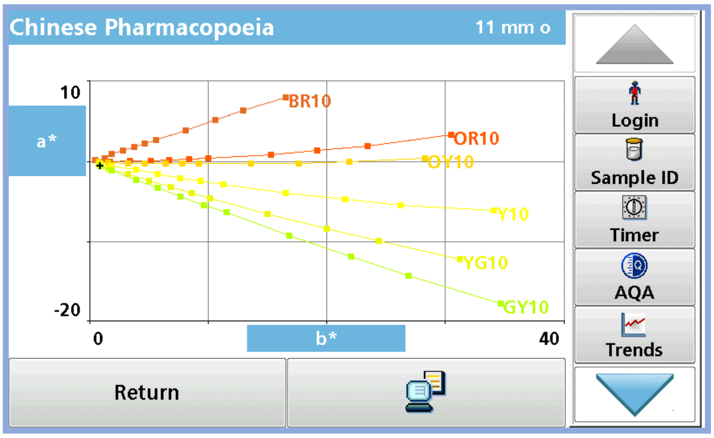


LICO 690 offers a display of the color graph and a selection option menu for the color scale so that the operator can choose one out of the six color scales for the evaluation.



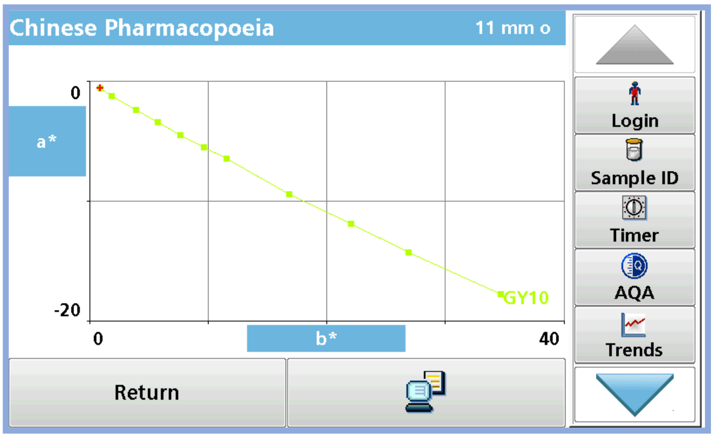
The comparison mode "Auto" (automatic comparison within all 66 CRS) can be used for the assessment or if a ChP method requires a color assessment in a specific color, this specify single scale can be selected for the assessment (BR, OR, OY, Y, YG or GY).

A push of the button "Graph" opens a new window which displays a CIE-ab* graph of the CRS's and a cross of the sample's location. The graph can be printed together with the color values and sample ID and User.



If "**Auto**" is selected and the button "**Graph**" touched a CIE-ab* graphic of the loci of <u>all</u> 66 CRS standards is display. The black " + " shows the location of the measured sample.

If "**GY**" is selected and the button "**Graph**" touched a CIE-ab* graphic of the loci of the GY standards will be display.



The following graph shows the loci of the 66 CRS in the CIE-Lab-system (11mm vial):

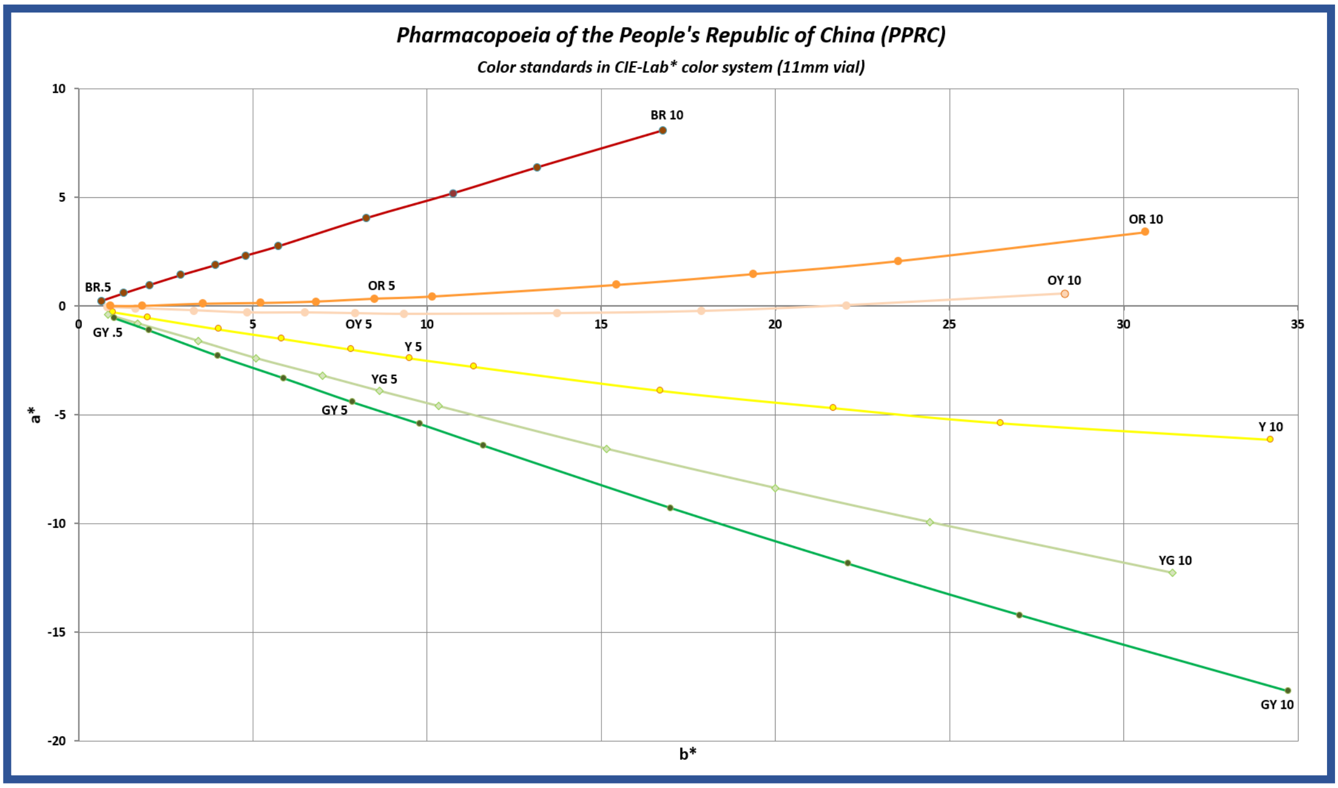


Fig. 3: Location of the ChP-color solutions in the CIE-Lab-system (11mm vial)

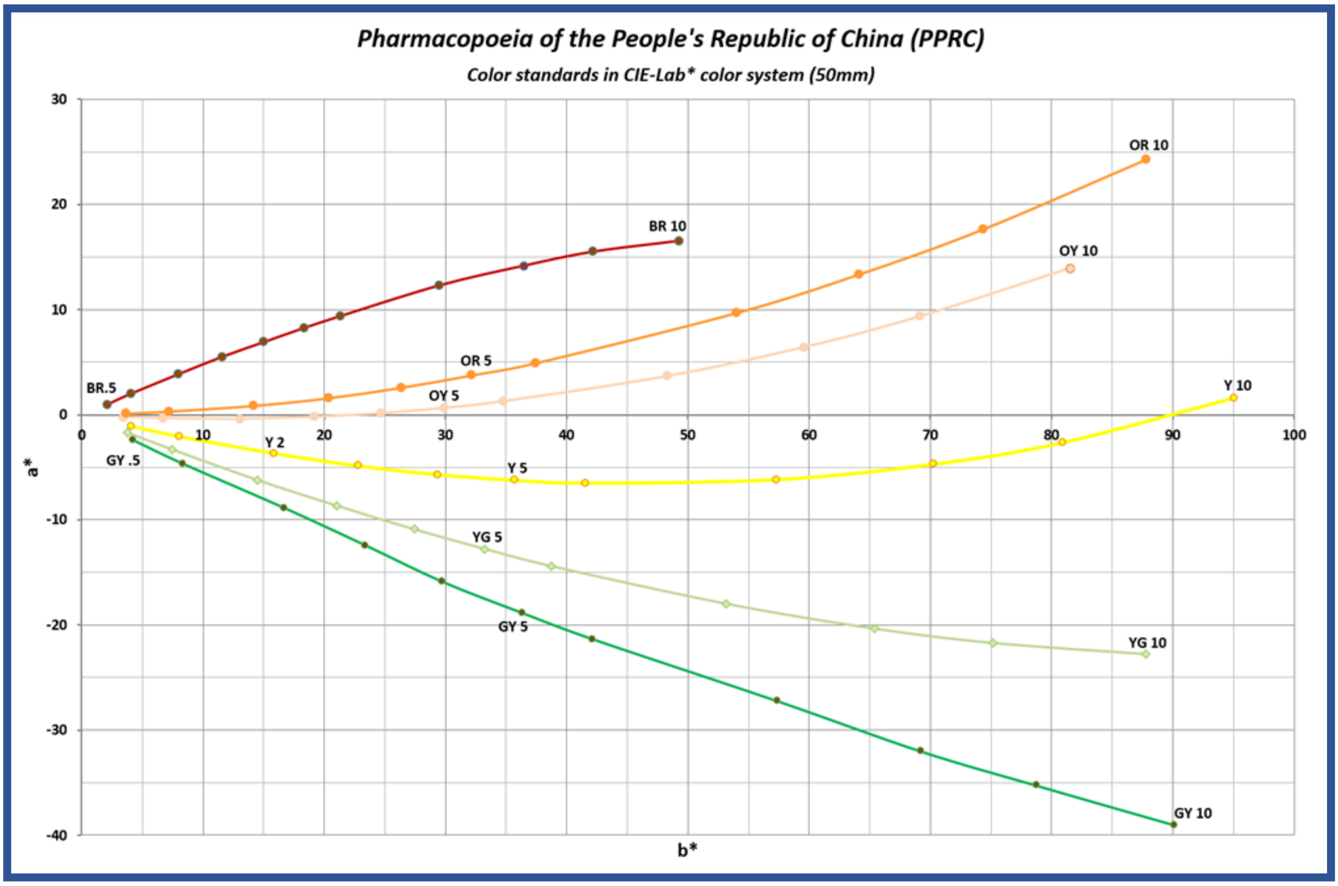


Fig. 4: Location of the ChP-color solutions in the CIE-Lab-system (50mm sample cell)

A detailed validation report for the ChP color evaluation is available and can be requested through the Hach Techsupport.

A2.9 The Klett Color Number

In contrast to the color numbers described above, the Klett color number itself is a photometric measured absorbance value. It is derived from an American Klett-Summerson photometer and is mainly employed for the assessment of raw material in the cosmetic industry. Usually, the Klett-color number identifies the light absorption of a sample liquid in a square cuvette of 4cm (or 2cm) path length measured through a blue filter (filter no. 42). For the Klett-Summerson photometer instruments, green and red filters are available too, but not considered here in the LICO calculation.

A2.10 The Hess-Ives Color Number

The Hess-Ives color number is used in the cosmetic industry for the assessment of fat derivates. It combines the weighted chromas which represent the red, green and blue shares of the transmission spectrum of the measured sample at three wavelengths in one single value. It is defined in the DGK[7]-method no. F 050.2. and LICO 690 calculates the result according to this method. The Hess-Ives-value is calculated by:

$$\text{H-I} = \frac{(R + G + B) * 6}{\text{layerthickness}} \qquad \textbf{(3)}$$

R, G and B are the color components for the red (640 nm), green (560nm) and blue (464nm) shares, where R, G and B:

$$R = 43{,}45 * E_{640} \ ; \ G = 162{,}38 * E_{560} \ ; \ B = 22{,}89 * \frac{E_{460} + E_{470}}{2}$$

A2.11 The Yellowness-Index

Originally, the Yellowness-Index acc. to ASTM D1925 was a dimension figure used in reflectance color measurement to describe the yellow cast of a reflecting surface (e.g. plastic, paper). The new ASTM D5386-93b [11] now defines the Yellowness-Index also for transparent liquids based on CIE XYZ-tristimulus values, standard illuminant C and the 2°-standard observer.

$$Yi = 100 * \frac{Tx - Tz}{Ty} \qquad \textbf{(4)}$$

[7] Deutsche Gesellschaft für wissenschaftliche und angewandte Kosmetik

A2.12 The ADMI Color Number

The American Dye Manufacturers Institute (ADMI) has adopted the Platinum-Cobalt color standard of the American Public Health Association (APHA) as the standard for color value. Although the Platinum-Cobalt standard is yellow-brownish colored, the ADMI method works for all colorations independent of the color hue. The ADMI Color is used for true color determination of water and wastewater having color characteristics significantly different from platinum-cobalt color due to the colorants used by textile production, as well as to those similar in hue to the standards. "*True color*" describes the color of water with removed turbidity and particles by filtration or another sample preparation.

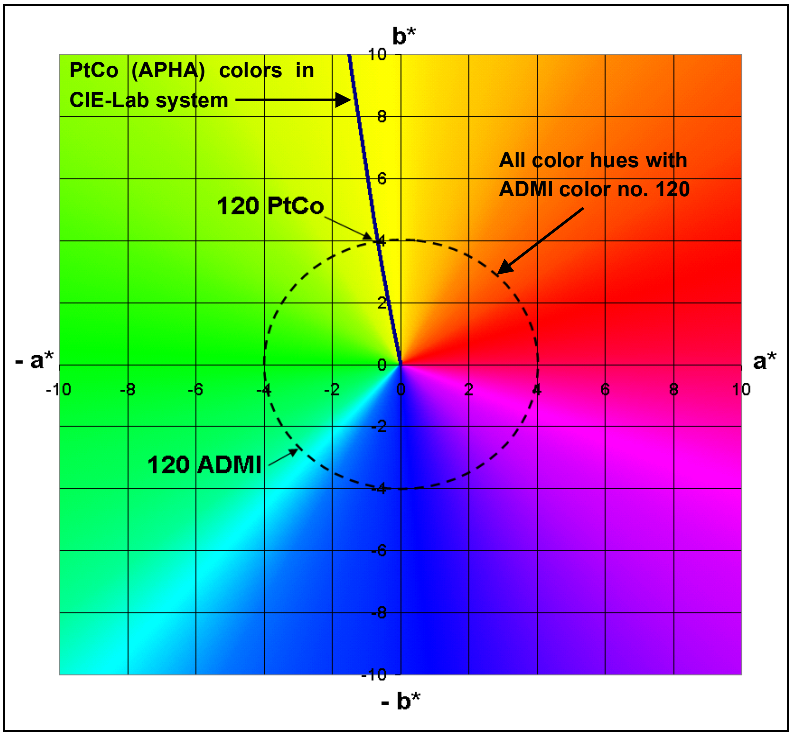
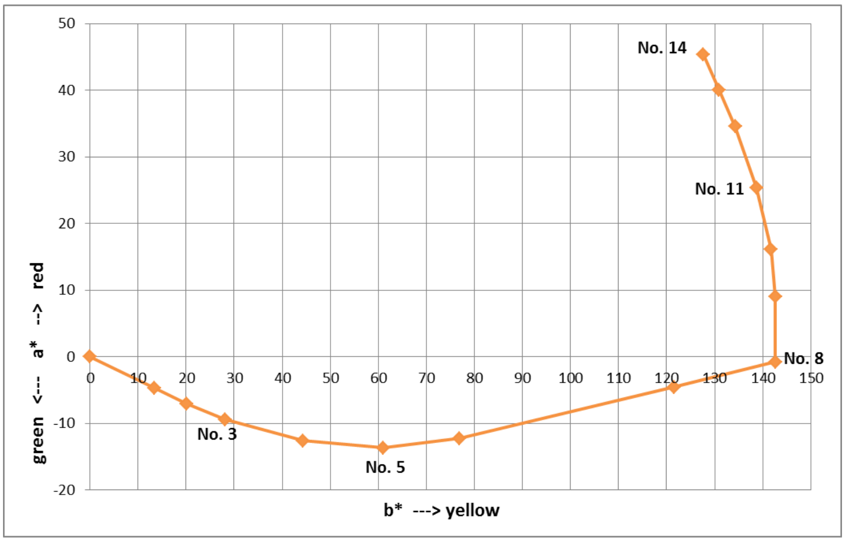


Fig. 5: ADMI Color definition

The reason for developing this method in the 70th is obviously the disadvantage of the visual color comparison if the hue of the sample liquid is different to the yellow-brownish hue of the liquid standard. The value of the ADMI color number is comparable to the platinum-cobalt color number and is a result of the comparison of the color strength of the sample liquid with the adequate color strength of the platinum-cobalt standard. So, if a platinum-cobalt standard of e.g. 120 is measured according to the ADMI color number the reading will be 120 ADMI. The ADMI value given by LICO 690 is independent of the layer thickness of the sample cell. The ADMI color range is 0 to 1000 ADMI. 10mm, 11mm and 50mm sample cells can be used for the measurement but for color values smaller than 100, a 50mm cell path length is recommended. Turbid samples must be filtered prior to analysis. Report the ADMI color values at pH 7 and at the original pH.

A2.13 The Acid Wash Color Determination

The Standard Test Method ASTM D848 for Acid Wash Color of Industrial Aromatic Hydrocarbons covers the determination of the acid wash color of benzene, toluene, xylenes, refined solvent naphthas, and similar industrial aromatic hydrocarbons. The values stated in SI units are to be regarded as standard. The color developed in the acid layer gives an indication of impurities which if sulfonated would cause the material to be discolored. The color numbers of the 14 reference color standards are stored in the LICO 690 instrument. Sample the test material in accordance with Practice D3437 and prepare it according to chapter 12 of the test method.



The LICO 690 designates the color of the acid layer by the number of the nearest reference color standard, following the number with a plus or minus sign if the sample is darker or lighter than the standard. Disregard any difference in hue and determine only whether the color of the acid layer is darker or lighter than the color of the reference standard to which the sample most nearly corresponds. If the hue of the acid color is different from the hue of the reference color standard, the color number will follow a (X). Thus “No. 4 − (X)” means that the acid wash test color is slightly lighter than No. 4 color reference standard and that the hue of the No. 4 color standard is not the same as the hue of the acid layer.

A2.14 The ASBC and EBC brewery Color Number

There are two separate methods for determining the color of beer and malt defined by the MEBAK[8] (visual method and spectrophotometric method). The two methods are similar, particularly when measuring pale beers, but not identical. Regrettably both methods using the same color unit – the EBC value (= **E**uropean **B**rewery **C**onvention) – and it is not visible which method was used for the color determination. LICO 690 enables an evaluation based on both the visual and spectrophotometric method. In an ideal case, the subjective perception of the eye is eliminated when the beer samples are compared thanks to the use of a photometer with a wide-band filter (Z or blue filter). The method has been standardized by defining the receiver and lighting characteristics in conformity with international color measurement standards. This is achieved using a special wide-band filter, which simulates light type B (sunlight) and the standard spectral function Z (sensitivity of the human eye in the blue part of the spectrum in conformity with ISO 11664, see fig. 9). Based on the visual method, three different evaluations are used (EBC I, EBC II and EBC wort) for pale beers, dark beers and congress worts.

The spectrophotometric method based on an absorbance measurement of the sample liquid in a 1 cm cell at 430nm. LICO 690 corrects the EBC value automatically by Beer´s law when a different path length is used for the measurement. If the sample is measured in a 50mm cuvette the factor used for the calculation is just 5.

$$EBC_{Phot} = 25 \, x \, E_{430} \quad \textbf{(5)}$$

[8] Mitteleuropäische Brautechnische Analysenkommission

The ASBC[9] developed a similar photometric method based on an absorbance measurement of the sample liquid in a 1 cm cell at 430nm. LICO 690 corrects the ASBC value automatically by Beer´s law when a different path length is used for the measurement.

$$ASBC = 12.7 \; x \; E_{430} \qquad \textbf{(6)}$$

Measuring range of LICO 500/690:

0 ≤ EBC I ≤ 60	0 ≤ EBC Whisky ≤ 85
0 ≤ EBC II ≤ 120	0 ≤ EBC-Phot ≤ 30
0 ≤ EBC Wort ≤ 50	0 ≤ ASBC ≤ 25

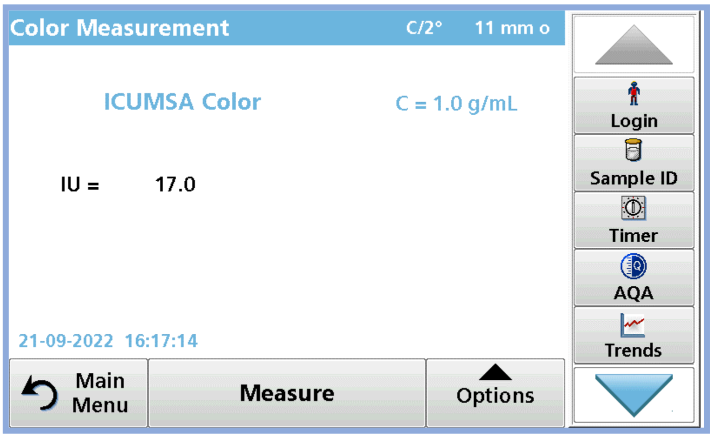
A2.15 ICUMSA Sugar Color Score

Typically, sugar is created from tropical sugarcane plants. They are crushed and their juice is extracted. It is then heated in a process that yields molasses. The molasses contains very dark sugar crystals. Manufacturers spin that in a centrifuge to remove the molasses and produce white sugar. White sugar comes in a number of different granule sizes, but most recipes call for granulated white sugar which features medium-sized granules. Sometimes it is called table sugar. Brown sugar is available in a variety of colors, ranging from light to dark brown. The flavour of brown sugar is very strong and should be soft and moist right out of the packaging. Decades ago, brown sugar was simply white sugar before all of the molasses was taken out, but now it is white sugar combine with the molasses that was separated from the original sugarcane. The darker the brown sugar, the more molasses is in the mixture. The International Commission for Uniform Methods of Sugar Analysis (ICUMSA[10]) is based in England and defines and develops individual standard measurement methods for classifying and quantifying the different characteristics of sugar. The ICUMSA Method GS 2/3-10 defines the measurement procedure to determine the whiteness of sugar. This method is called “The Determination of White Sugar Solution Colour” and was the first time included in Supplement 2011. The determination of the Solution Colour of Raw Sugars, Brown Sugars and colored Syrups at pH 7.0 is defined in the official ICUMSA Method GS 1/3-7.

Refined sugar is widely used for industrial needs for higher quality. Refined sugar is purer (ICUMSA values below 300) than raw sugar (ICUMSA values over 1,500). The level of purity associated with the colors of sugar, expressed by standard number ICUMSA, the smaller ICUMSA numbers indicate the higher purity of sugar.

The measurement of color of sugar in solution can be applied to all types of sugar from white to brown out of the affination centrifugals. For white Sugar Solutions, the use of 420nm as the wavelength for color measurements is recommended abandon from the fact that an absorbance value on a single spectral wavelength isn´t sufficient for a full visual or photometric color assessment. A single absorbance value at 420nm (which is in the lower blue range of the full visible spectrum) gives no information about total appearance of the sugar sample. A full wavelength scan from 380nm to 720 nm and a calculation of the CIE-Lab values would give a much better numeric description and determination of the true color of the sugar. For darker, brown sugars a wavelength of 560nm should be used.

[9] American Society of Brewing Chemists
[10] International Commission for Uniform Methods of Sugar Analysis



A 50 Brix sugar solution is prepared by a 50:50 mixture of solid sugar in filtered water. For example, 10 g of sugar are dissolved in 10 ml of water. This solution should be filtered (0.45µ filter) and then measured with LICO.

The LICO 690 calculates and displays the ICUMSA color value of a sugar sample according to the Method GS 2/3-10. If the Brix value of a sample is different from 50 (1g/ml) the actual concentration of the sample can be entered in a pop-up window touching the "C =" area on the screen.

From the absorbance values of the wavelengths 420nm, the ICUMSA value (IU) is calculated using the following formula:

$$ICUMSA_{420} = \frac{A_{420} * 1000}{c * l_{(cm)}}$$

A = absorbance at wavelength
C = concentration of sugar in g/ml
l = path length of the sample cuvette (10/11/50mm)

The color measurements can optionally be carried out with disposable glass or plastic cuvettes with an optical path length of 10 mm, 11 mm or 50 mm, so that any rinsing and cleaning effort is dispensed with. Adjust the pH of the sample to 7. The test sample must be clear and free of moisture, haze, and particulate matter.

B The Principles of Objective Color Measurement

As early as in 1931, the colorimetric principles were laid down on an international level by standardising light sources, a standard observer and a color identification system known as CIE[11]-color system. To understand terms and abbreviations like e.g. C/2° or D_{65} and to employ the CIE-color system correctly, the following definitions must be known.

Figure 6 shows the basic color perceptions:

a) Reflexion

b) Transmission

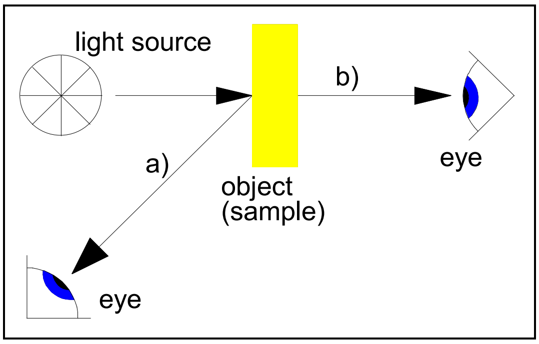


Fig. 6: Color perceptions

Color assessment by reflexion (a) is used for solid, opaque products like e.g. plastic parts, painted surfaces, textiles or also printed packing's. In today's practice, colorimeters featuring measuring geometries 45°/0° or diffuse/8° are employed.

The colors of liquid and transparent products or raw materials like e.g. resins, surfactants, oils, fatty acids, detergents, glycols and glycerines are usually determined by transmission (b).

As shown in figure 6, pigment colors can only be determined when there is a light source, an object and an observer. To make color assessment objective, the surrounding factors like „light source, observer and optical set-up“ must be defined in a corresponding standard.

B1 The human eye

The human eye is a highly sensitive sense organ capable of discerning about one million color hues and detecting even the slightest deviation in direct comparison of reference and sample colors.

For visual color assessment, however, the eye is reliable only to a certain extent, because changing ambient conditions and the mood of the observer are easy to influence.

What is more, about 8% of males and 0.5% of females have an abnormal color vision, which may lead to wrong color assessment.

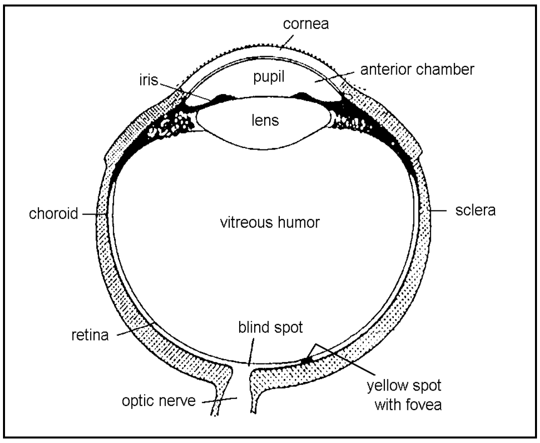


Fig. 7: Structure of the human eye

[11] Commission Internationale de l'Eclairage

The retina of the human eye (Fig. 88) contains light-sensitive cones cells for daytime color vision (light-adapted eye) and so-called rods for night-vision (dark-adapted eye).

The cones cells are subdivided into red, green and blue sensitive ones. The rods have no influence on color vision. They receive only light/dark signals.

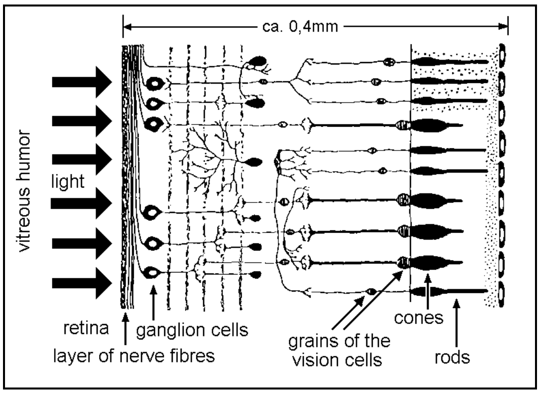


Fig. 8: The retina

ISO 11664-1 defines the spectral color sensitivities of the three cone cell types for a light-adapted eye (i.e. for daytime color vision with the cones). In this connection, the term of "colorimetric standard observer" is employed. The spectral sensitivities of the cone cells are termed standard spectral functions (Fig. 9) and stated in numbers as x(λ), y(λ) and z (λ), where λ is the wave-length. But the statistical distribution of rods and cones over the retina is not even. In the centre, i.e. opposite the pupil, there are only color sensitive cones which are gradually replaced to-wards the outside by rods.

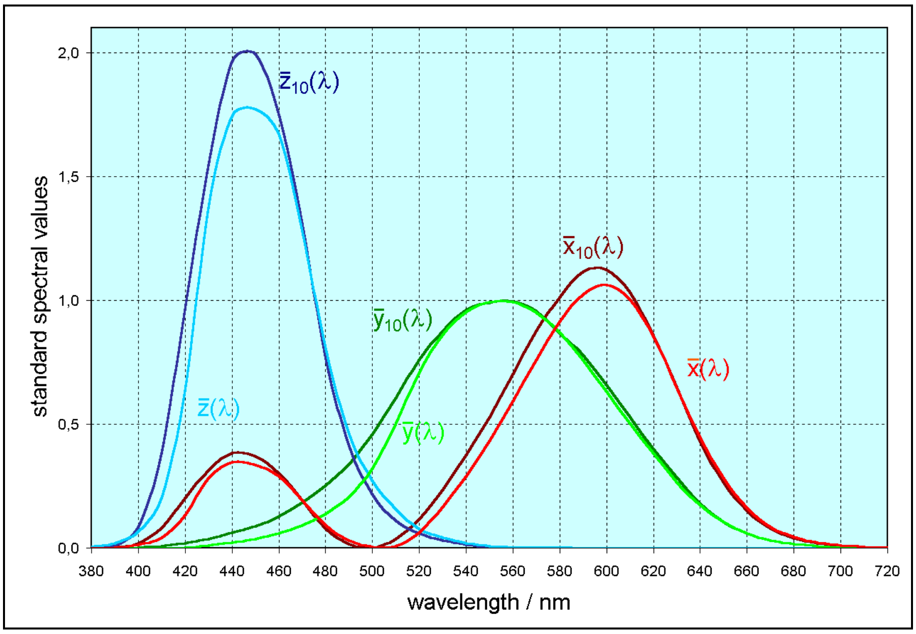


Fig. 9: CIE color matching functions x(λ), y(λ) and z(λ)

Therefore, color perception (or color stimulus) depend on the observer's field of view and changes with the size of the surface to be assessed. Owing to this change in the color stimulus when observing colored surfaces of different sizes, ISO 11664-1 defined a 2°-standard observer in 1931 and a 10°-standard observer in 1964. The 2 °-standard observers evaluate a coin-size colored surface at a distance of 50cm, whereas the 10 °- observers evaluates a postcard-size surface at the same distance. To differentiate between the measuring of the 2° and 10°-observers, the 10°-values are marked with an index (10).

B2 The influence of light on color perception

The eye perceives only a small part of the electromagnetic radiation at wavelengths between 380 nm and 720 nm (nm = nano meter = 10^{-9}m).

The spectral characteristic and color temperature of the light source play an important role in the assessment of colors, too. A red, yellow or blue light source is useless for color assessment because it emits only a part of the perceptible radiation which makes the illuminated sample reflect only this part in turn.

The color temperature influences the whiteness of the light source. Standard illuminant A was defined as early as in 1931 and corresponds to the spectral function of a 100W tungsten lamp emitting a color temperature of approx. 2800 Kelvin. Illuminant C has a color temperature of 5600 Kelvin and standard illuminant D_{65} of 6500 Kelvin. The main difference between the standard illuminant C and D_{65} is the fact, that in the near UV-range (300 to 400nm) the standard illuminant D_{65} has an ultra-violet radiation intensity similar to natural sunlight.

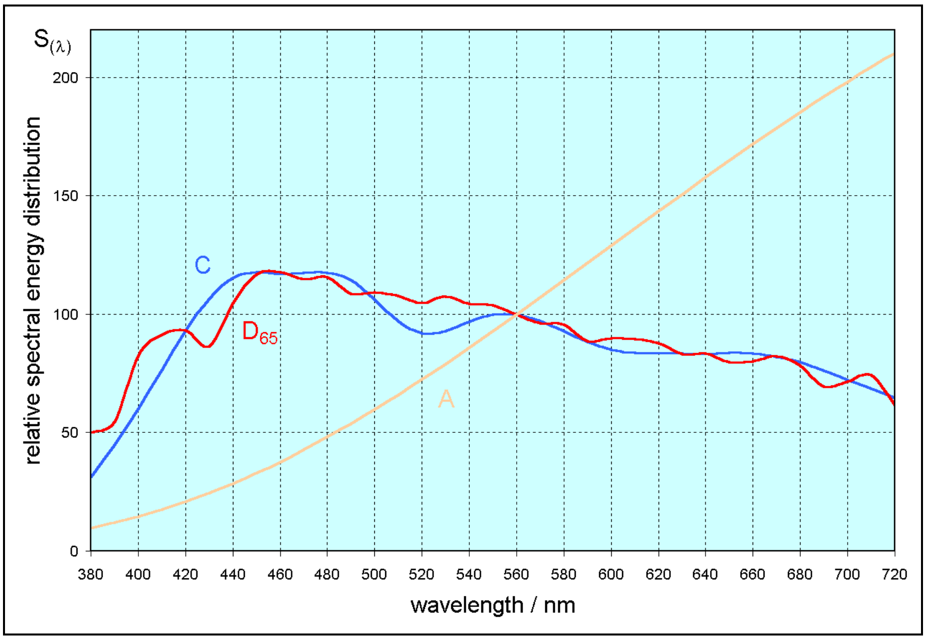


Fig. 10: CIE Standard illuminants A, C and D_{65}

The relative spectral power distributions S(λ) for the standard illuminants A, C and D_{65} are defined by ISO 11664 (Fig. 10, Standard illuminant A, C and D_{65}).

B3 Methods of color measurement

Basically, there are three different methods to assess colors in the lab:

- visual color matching
- tristimulus method
- spectral method

B3.1 Visual color matching

Visual color matching means to compare sample and reference colors just by the human eye. In fact, this procedure is not a measurement and cannot provide objective results. It is mainly employed for transparent liquids where the product is compared with reference solutions (like Iodine, Hazen or Gardner color standards). Nevertheless, these liquid standards are colorfast only for a limited period, i.e. they change hue by the influence of light and must be replaced after six months at the latest, depending on how they are stored. The only alternative to liquid standards were additional devices, the so-called comparators, permitting visual color matching of the samples using colored glass or color dots. The main disadvantages of visual color matching are, among others, the subjective factors (abnormal color vision of the color matcher or bad and unsteady illumination) and the difficult assessment of hue deviations by red or green stains between sample and reference. It is true that standard regulations explicitly prevent the latter case by stating that only products similar in hue to the reference solution may be evaluated by these methods, but in practice, this instruction is often not observed, because the term "similar" leaves room for interpretation.

B3.2 The tristimulus method

In the tristimulus method is a simple filter photometric construction where the transmitted light beam is dispersed after passing the sample into its red, green and blue proportions by 3 color filters which are adapted to the color sensitivity of the human eye. The transmission intensity is measured by photoreceptors. A reference beam path makes sure that disturbances by e.g. lamp or temperature drifts will be compensated.

The measured signal indicates transmittances Tx, Ty or Tz, depending on the color filter employed (X, Y or Z).

From these transmittances, the standard tristimulus values can be determined by equations (7) to (9).

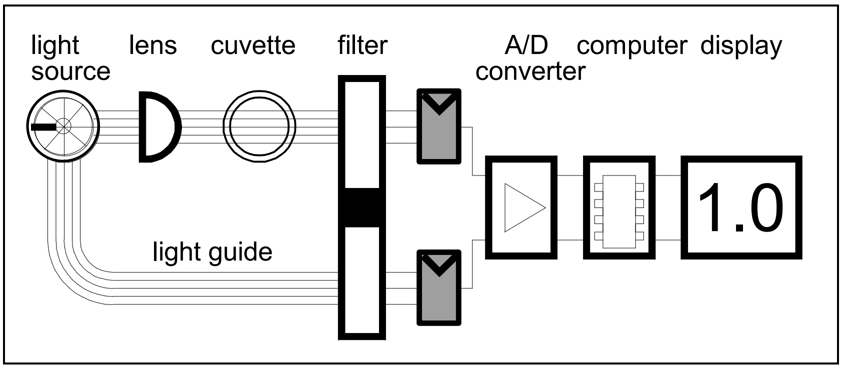


Fig. 11: Beam path of a filter photometer

As factors a, b and c depend on illuminant and observer, they must be put in correspondingly.

$$X = a * Tx + b * Tz \quad (7)$$

$$Y = Ty \quad (8)$$

$$Z = c * Tz \quad (9)$$

B3.3 The spectral color measurement method

In the spectral method, light is dispersed into its spectral proportions with a concave grid and the transmittance $\tau(\lambda)$ of the sample is measured at intervals of 10nm. Standard tristimulus values X, Y and Z are calculated from the chosen standard illuminant $S(\lambda)$, standard spectral functions $x(\lambda)$, $y(\lambda)$ and $z(\lambda)$ and the transmittances $\tau(\lambda)$ by equations (10) to (12) (see ISO 11664).

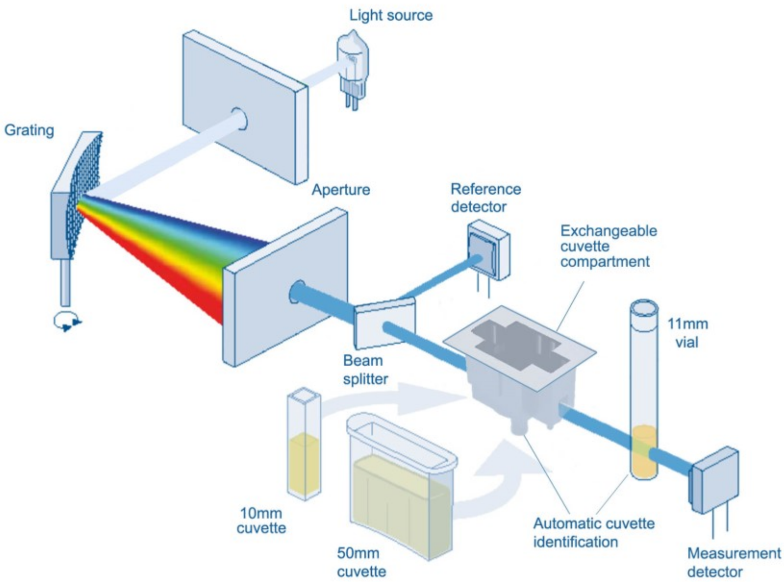


Fig. 12: Measuring principle of LICO 690

$$X = k * \int_{\lambda=380}^{720} S(\lambda) * \bar{x}(\lambda) * \tau(\lambda)\, d\lambda \quad (10)$$

$$Y = k * \int_{\lambda=380}^{720} S(\lambda) * \bar{y}(\lambda) * \tau(\lambda)\, d\lambda \quad (11)$$

$$Z = k * \int_{\lambda=380}^{720} S(\lambda) * \bar{z}(\lambda) * \tau(\lambda)\, d\lambda \quad (12)$$

Factor k (equation (13)) serves to standardize tristimulus value Y for perfect white ($\tau(\lambda)=1$). Therefore, tristimulus value Y_n is always 100 for all combinations of the standard illuminants and standard observers.

In practice, the infinitely small intervals $d\lambda$ are converted into limited intervals $\Delta\lambda$ (usually in steps of 10nm) and integrals (10) to (12) are converted into summation equations.

$$k = \frac{100}{\int_{\lambda=380}^{720} S(\lambda) * \bar{y}(\lambda) * d\lambda} \quad (13)$$

Standard tristimulus values X, Y and Z are the fundamentals of colorimetry and used for all further mathematical calculation of color values. But the tristimulus values alone do not give any direct information on lightness, hue or chroma of a color. Therefore, they are transformed to other colorimetric systems such as CIE-Lab, CIE-Luv, Hunter-Lab, etc.

B4 Colorimetry and standard color systems

Colorimetry is employed to determine transmittances T_{380} to T_{720} (spectral method) or transmittances Tx, Ty and Tz (tristimulus or filter method). When these values are known, the color itself is measured. Just like geometry describes the relation of a point within a three-dimensional Cartesian system, colorimetry describes a spectrum locus within the color space of real colors. Standard tristimulus values X, Y and Z are calculated by the a.m. equations as shown in the examples. They are the fundamentals of colorimetry. As standard tristimulus values X, Y and Z form no rectangular coordinate system (triangle coordinate) and give no direct information about lightness, hue and chroma of a sample, they are transformed to other (rectangular) color systems for better understanding and graphical representation. By and by, several theories on human color perception were introduced and dozens of color systems developed. We will confine ourselves to show just the most important ones for practical use. ISO 11664 part 4 defines the CIE 1976 Lab*-color space.

B4.1 The CIE 1931 Color Space (tristimulus system)

One of the first mathematically defined color spaces was the CIE 1931 XYZ color space, created by the International Commission on Illumination (CIE) in 1931. The chromaticity coordinates x and y (say: small x and small y) in the tristimulus system are calculated from the standard tristimulus values X, Y and Z by the following equation:

$$x = \frac{X}{X+Y+Z} \qquad \textbf{(14)} \qquad\qquad y = \frac{Y}{X+Y+Z} \qquad \textbf{(15)}$$

If you mark chromaticity coordinates x and y for all real body colors in a diagram, you will receive a solid bounded by the loci of the spectral colors (Fig. 13). One level of the color space shows only colors of equal lightness. The loci of colors differing in lightness will therefore lie on different levels. In practice, however, colors of different lightness are marked on the same level of a color chart with the numeric lightness values. A graphic display including lightness, hue and saturation of a trichromatic stimulus calls for a spatial representation (Fig. 14).

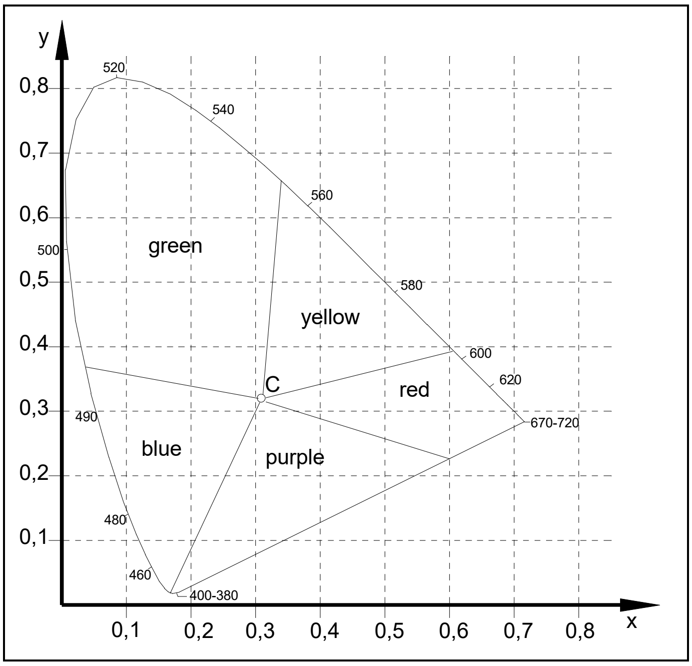


Fig. 13: Chromaticity diagram of the tristimulus values

The third axis is in vertical position toward the xy-plane and is calculated / indicated by the tristimulus value Y. The color solid is bounded by the pure spectral colors. The loci of all real colors lie within the color solid. As a rule, the standard observer used for measuring or calculating must be taken into account for any graphic representation, because graph and spectrum location of the light source differ for 2° and 10° standard observers.

A more telling representation than the tristimulus system is the L*a*b*-color space (Fig. 155).

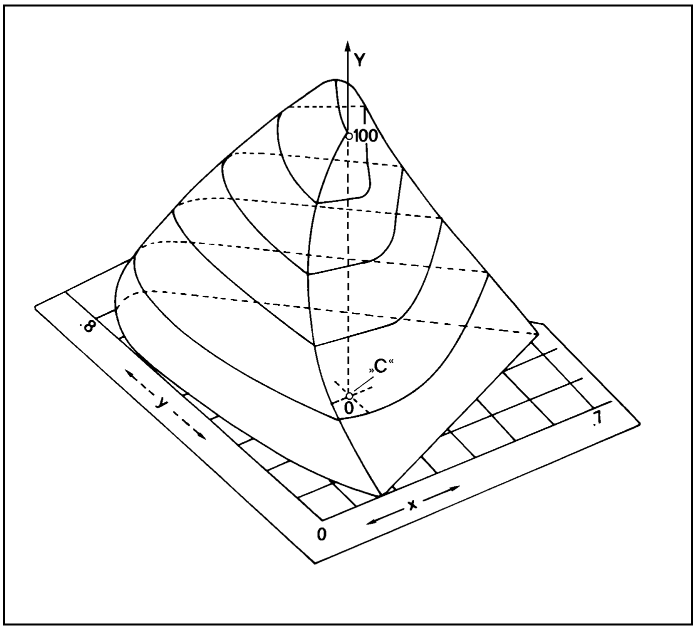


Fig. 14: Three-dimensional color space with Y-axis

B4.2 The CIE-Lab-system

The CIE[12]-Lab-system is also specified by the International Commission on Illumination and defined in ISO 11664 part 4 “CIE 1976 Lab Colour space” is in better harmony with subjective color perception. Since the CIE-Lab model is a three-dimensional model, it can only be represented properly in a three-

[12] Commission Internationale de l'Eclairage

dimensional space. It describes all the colors visible to the human eye and was defined in the 1976 to serve as a device independent color model to be used as a reference.

The L*-axis gives the lightness of a color, the a*-axis the red-green and the b*-axis the yellow-blue share. The L*-values are always positive and lie between 0 for ideal black colors and 100 for ideal white ones. Red hues have positive a*-values, green ones negative a*-values accordingly. Yellow hues have positive b*-values, blue ones have negative b*-values.

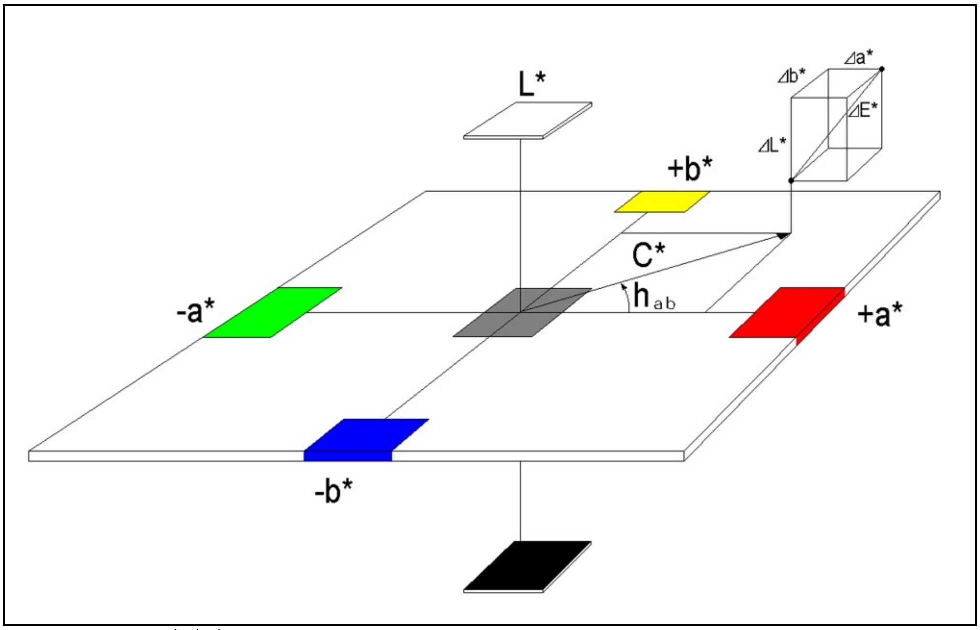


Fig. 15: CIE-L*a*b*-System ISO 11664 - 4

Color loci distributed in a circle around the L*-axis have the same C* (chroma), but different h (hue). Color loci lying on a radius beam starting from the L*-axis are equal in hue h, but of increasing chroma. The angle between radius beam and the positive a*-axis is defined as hue h_{ab}, stated in angular degrees between 0° and 360° and counted in mathematically positive sense (anticlockwise). The L* component closely matches human perception of lightness. A middle gray color will be read as L* = 50.

The CIE-Lab-values are calculated from the standard tristimulus values by equations (16) to (20) and therefore depend on the employed illuminant (A, C or D_{65}) and standard observer (2° or 10°), too.

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

$$a^* = 500 * \left(\sqrt[3]{\frac{X}{X_n}} - \sqrt[3]{\frac{Y}{Y_n}} \right) \quad \textbf{(17)}$$

$$b^* = 200 * \left(\sqrt[3]{\frac{Y}{Y_n}} - \sqrt[3]{\frac{Z}{Z_n}} \right) \quad \textbf{(18)}$$

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad \textbf{(19)}$$

$$h_{ab} = \arctan\frac{b^*}{a^*} \quad \textbf{(20)}$$

B4.3 The Hunter-Lab-system

The Hunter-Lab-color scale has been used for the assessment of surface colors since 1960, mostly in the USA. The color coordinates are similar to the CIE-L*a*b*-scale but not identical. The Hunter-Lab-color values are calculated from standard tristimulus values X, Y and Z, but with different equations. The color space is related to the CIE-Lab space in purpose, but differs in implementation.

B5 DIN EN 1557

On the basis of ISO 11664, the DIN EN 1557[3] also define a colorimetric characterization of optical clear colored liquids to replace conventional visual color scales[17]. For this colorimetric characterization, the transmittance of a liquid is measured in a 1cm sample cell and the X, Y and Z are determined and reported. The calculation of color values according to this standard is referred to standard illuminant C and 2°-observer. The transmittances values can either be used directly (e.g. for production control) or transformed to other CIE-color scales, e.g. CIE-Lab*. Fig. 16 compares the EN 1557-standardized transmittance Tz and the visual color scales The comparison of visual color systems lacks precision owing to hue difference between the systems. The Fig. 16 is just supposed to give a general idea of the scales and the correlations.

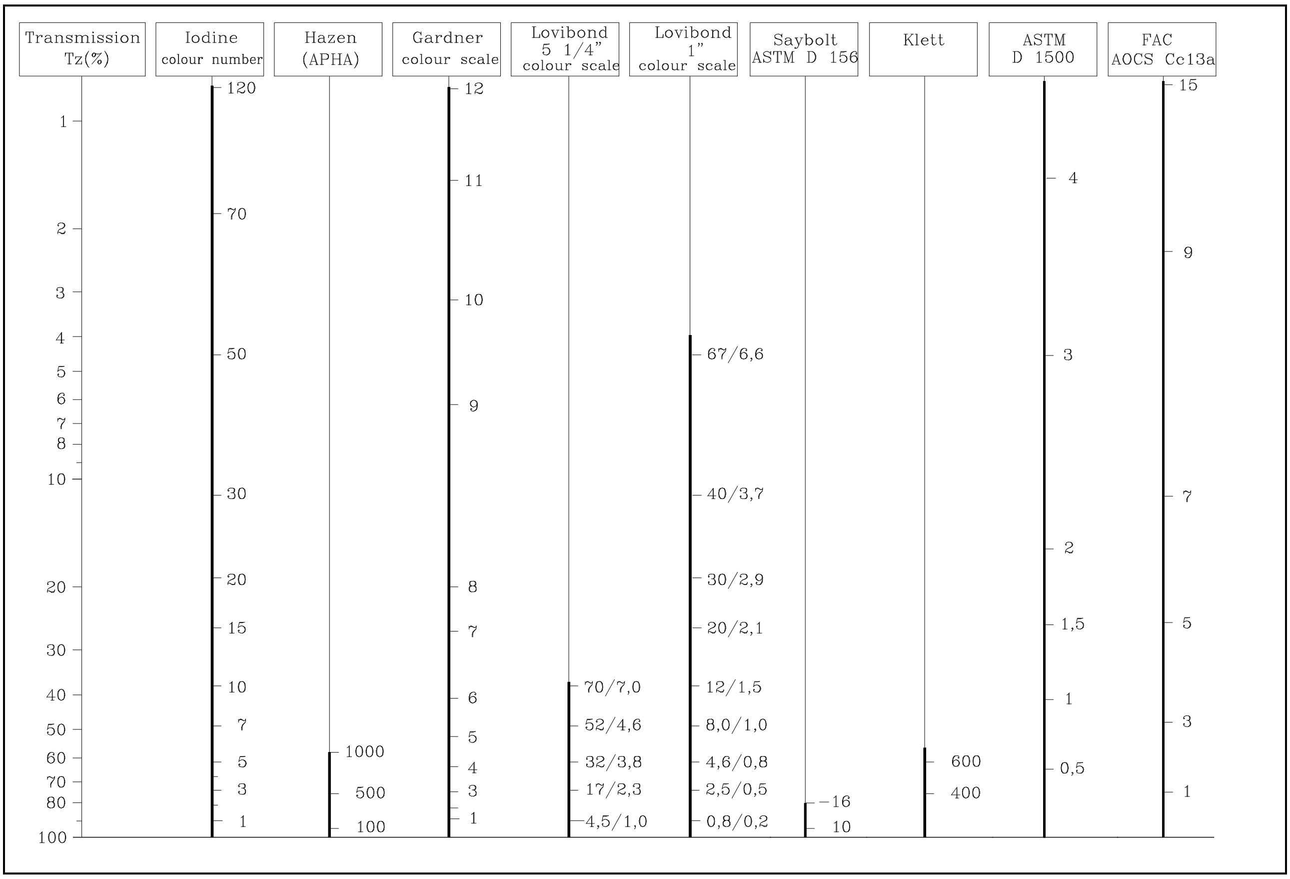
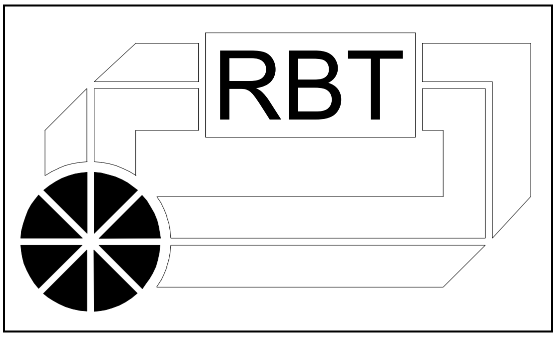


Fig. 16: Comparison of visual color systems with the Z-transmittances

C Instruments for color measurement of clear liquids

Hach Lange colorimeters are high-quality optical instruments using perfected and well-proven technologies. Thanks to their very simple handling and universal application, they are the best choice for routine checks at the goods receipt department, in production and quality control. All instruments feature a modern optical system with reference beam technology (RBT) to automatically compensate disturbances cause by e.g. lamp aging or temperature changes.



C1 The LICO 690

The LICO 690 is a spectral colorimeter which has been specially designed to evaluate the color numbers and measure the colors of transparent liquids in conformity with EN 1557. LICO 690 is the new benchmark for top reliability and unique operator friendliness through menu-controlled user guidance on the large graphic display and fully automatic measurement. It functions in accordance with the described method with standard light type C and 2° standard observer but supports also light sources A and D65 as well as 10° standard observer.

The LICO 690 can be used for quality control and production control in almost all areas of the chemical, cosmetic and pharmaceutical industries, e.g. for assessing surfactants, oils, fats, resins and synthetic resins or pharmaceutical active substances.

Fig. 17: LICO 690

LICO 690-Features:

- Automatic cuvette detection for
- 10, 11, 50mm cuvette type with
- Sample volume of only 3 to 5 ml
- Exchangeable cell compartment
- Backlit color touch display
- User profiles with password protection
- GLP-conformable print-out
- Integrated test media control
- Backup and restore function
- “Speaks” more than 15 languages

LICO 690 replaces conventional visual color assessment by fast and objective color measurement. For Hazen color evaluation of water-white liquids in particular, e.g. glycols, glycerol's, paraffin's with colorations below 100 Hazen and color determination to the European pharmacopoeias, 50mm rectangular cuvettes can also be used. All color measurements and color number determinations with the LICO 690 can be carried out with inexpensive glass or plastic disposable cuvettes with 10 mm, 11mm or 50 mm path length, thus eliminating the need for rinsing and cleaning. Sample volumes of only 3 to 5 ml are needed. If necessary, products with higher melting points, such as fatty acids or paraffin, can be heated with a small Hach Lange thermostat before the measurement is carried out. With integrated test equipment monitoring and the use of certified test filters, LICO 690 satisfies all the demands made on an AQA quality assurance system to ISO 9001.

The intuitive instrument operation enables a quick and easy determination of all conventional color numbers. Measurements can also be carried out in line with the CIE L*a*b* system (DIN 6174), the European Pharmacopoeia, US Pharmacopoeia, Chinese Pharmacopoeia and all the usual photometric analyses in the wavelength range from 320 to 1100 nm are possible. The existing USB interfaces can be used to connect a printer, keyboard, memory stick for data storage, instrument backup and restore and firmware updates. An external USB barcode reader can also be connected for sample name readings. An USB A-port provides a connection to a PC and an Ethernet port provides connectivity to Networks and Internet.

C1.1 LICO 200

In 1991 Dr. Lange has launched the first instrument of the LICO series, the LICO 200. This instrument was the basis for the objective color measurement. LICO 200 offered all important color scales, a color difference measurement mode and photometric functionality for analytical purposes. Today, about 28 years after the first deployment, LICO instruments are in use worldwide in much more than 1000 laboratories and production sites.

In 1997 the LICO 200 was replaced by LICO 300 and in 2001 by LICO 400. LICO 500 followed in 2007 with new features and technologies, color touch screen, USB port, open cell compartment and additional color scales. End of 2012 the most recent version LICO 690 was launched.

Fig. 18: LICO 200

C2 The LICO 150 and it´s successor LICO 620

The LICO 150 and it´s successor LICO 620 is designed for fast routine measurements in the laboratory and in production facilities and is already in use in a wide variety of areas in the chemical, cosmetic and pharmaceutical Industries for quality and production control, e.g. to assess surfactants, oils, fats, resins and synthetic resins. It replaces traditional visual color assessment by fast and objective measurements and can be operated either with a wall power supply or optional with a Lithium Ion battery pack. An USB interface connector enables to connect a portable printer, a keyboard or an USB memory stick for data storage or firmware updates.

Fig. 19: LICO 150

The LICO 150 and it´s successor LICO 620 is supplied with the following color systems: Iodine, Hazen (PtCo/APHA), Gardner, Saybolt color number and ASTM D 1500.

The measurement procedure starts automatically when the round cuvette is placed into the vial compartment.

The automatic cuvette size detection offers always secure and reliable reading results displayed on the large graphic touch screen in terms of the selected color system.

An idle mode and a selectable automatic power-off option guarantees a long operation time and prevents the batteries from being run down unnecessarily. Simple operation, automatic calibration and the use of affordable disposable cuvettes make the LICO a cost-effective alternative to traditional visual measurement methods.

D Annex

D1 Test Media Inspection

Hach offers test filter sets for LICO as certified test media for inspection. They comply with the requirements of ISO 9001ff regarding test certificate, reference values and permissible tolerances, serial number, calibration date, validity and signature.

Additional safety is offered by a maintenance agreement which does not only ensure good function of the instrument but comprises more advantages like e.g. an extended guaranteed period of 5 years in total and free software-updates. Combined with these certified test media, Hach colorimeters are the best basis of a quality system in compliance with ISO 9000-9004 and GLP.

Fig. 20: Test filter set for LICO

D2 Cuvettes and Accessories

Five different types of cuvettes with three different path lengths are at choice for your color determination.

The cuvette type and material should be selected depending on the color intensity (water clear or tinted) and the type of sample (diluted, with solvent).

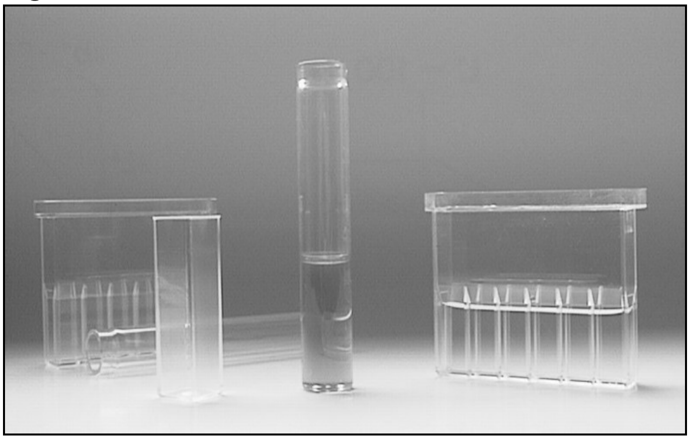


Fig. 21: Hach cuvettes for color measurement

The new sealable 50mm sample cell combines the handling advantage of a sealed sample vial with the precision of a 50mm optical path length and provides triple security for the user:

- Secure and reliable measurement results due to long beam path lengths,
- Safe sample cell handling with of no spillage risk due to a closed sample cell,
- Occupational safety with protection against off-gassing or premature evaporation of the sample liquid.

Fig. 22: Hach LZM381 50mm cuvettes with screw caps

The new sealable sample cell can be used for all LICO color application as a direct replacement of the existing 50mm plastic cuvette because the plastic material and the dimensions are the same.

The cuvette tray in the box is designed for multi purposes. The new unused cuvettes are fitted up-side-down in the tray to avoid any contamination by dust or particles. For filled or used cuvettes the tray can be used as a cuvette stand. The samples in the sealed cuvette can be directly used as retained samples or stored for long-term aging tests.

Cuvette type	10mm glass	10mm PS	11mm glass vial	50mm glass	50mm PMMA	50mm PMMA
Order no.	LYY215	LYY214	LYY621	LZP167	LZM130	LZM381
Dimensions (mm) inner (path length) outer	 10 x 10 12 x 12	 10 x 10 12 x 12	 11 ∅ 13,2 ∅	 50 x 10 52 x 12	 50 x 5 52 x 12	 50 x 5 52 x 12
Lid	-	-	EYG044			Screw cap
Filling volume approx.	2 ml	2 ml	2 ml	10 ml	5 ml	5 ml
Max. temperature	90° C	70° C	150° C	90° C	80° C	80° C
Pieces/pack	1	1000	560	1	50	20

For the disposable 11mm round glass vial a dryer thermostat is available to heat-up up to 15 cuvettes to temperatures of 40°C to 150°C.

Fig. 23: dry thermostat

D3 References

[1] ISO 11664 Colorimetry (ASTM E 308).

[2] ISO 11664-4 CIE 1976 L*a*b* Color space

[3] DIN 6162 Determination of iodine color number

[5] ISO 6271 Clear liquids; Estimation of color by the platinum-cobalt-scale (Hazen, APHA color number, also ASTM D 1045-58, ASTM D 268-49, ASTM D 1209-62, BS 2690:1956.).

[6] ISO 4630 Estimation of color of clear liquids by the Gardner color scale, also ASTM D 1544-80.

[7] Hess-Ives Bestimmung der Farbzahl nach Hess-Ives; DGK-Prüfmethode F 050.1.

[8] Ph. Eur European Pharmacopoeia, chapter 2.2.2 ″Coloration of Liquids″

[9] ASTM D 156 Standard Test Method for Saybolt Color of Petroleum Products
ASTM D 848 Standard Test Method for Acid Wash Color of Industrial Aromatic Hydrocarbons

[10] ASTM D 1500 Standard Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)

[11] ASTM D 5386 Standard Test Method for Color of Liquids Using Tristimulus Colorimetry.

[12] ASTM D 6045 Standard Test Method for Color of Petroleum Products by the Automatic Tristimulus Method.

[13] ASTM D 6166 Standard Test Method for Color of Naval Stores and Related Products (Instrumental Determination of Gardner Color).

[14] AOCS Cc 13a FAC Standard Color.

[15] AOCS Cc 13e Fats and fatty oils, Determination of color, also BS 684 1.14.

[16] ISO 27608 Animal and vegetable fats and oils - Determination of Lovibond color - Automatic method

[17] Möller-Kemsa J. Objective Color Assessment at Cosmetic Products, Euro Cosmetics 4/94.

D4 Technical Data of LICO Instruments

Instrument		LICO 690	LICO 500	LICO 400	LICO 300	LICO 620	LICO 150
Measuring system		spectral	spectral	spectral	spectral	spectral	spectral
Measuring geometry		0°/180°	0°/180°	0°/180°	0°/180°	0°/180°	0°/180°
Standard illuminant		A/C/D65	C	C	C	C	C
Standard observer		2° / 10°	2°	2°	2°	-	-
Halogen lamp		6V/10W	6V/10W	12V/20W	12V/20W	6V/10W	6V/10W
Reference beam path		•	•	•	•	•	•
Open cell compartment		•	•	•	-	•	•
10mm-square cuvette		•	•	•	•	•	•
11mm-round cuvette		•	•	•	•	•	•
50mm-square cuvette		•	•	•	•	•	•
Automatic cuvette detection		•	•	•	•	•	•
GLP-conformable print-out		•	•	•	•	•	•
AQA test menu and report		•	•	•	-	•	•
Certified test equipment		•	•	•	•	•	•
Evaluations, color scales and measuring range							
Standard tristimulus values XYZ	full	•	•	•	•	-	-
Chromaticity coordinates xyY	full	•	•	•	•	-	-
CIE-Lab-values L*a*b*C*h	full	•	•	•	•	-	-
CIE-Lab-difference values dE*		•	•	•	•	-	-
Hunter-Lab-values Lab	full	•	•	•	•	-	-
EU Pharmacopoeia color.	B, BY, Y, GY, R	•	•	•	•	-	-
USP color determination	A to T	•	•	•	-	-	-
Chinese Pharma color (ChP)	GY,OR,OY,Y,YG,BR	•	-	-	-	-	-
Transmittances TxTyTz	full	•	•	•	•	-	-
Iodine color number	0 to 120	•	•	•	•	•	•
Hazen color number	0 to 1000	•	•	•	•	•	•
Gardner color number	0 to 18	•	•	•	•	•	•
Lovibond® 1) yellow/red	Ly 0 - 120, Lr 0 - 20	•	•	•	•	-	-
Saybolt color number	+30 ... -16	•	•	•	•	•	•
Mineral oil color number	0 to 8	•	•	•	•	•	•
Klett color number	0 to 1000	•	•	•	•	-	-
Yellowness-Index Yi	full	•	•	•	•	-	-
Hess-Ives color number H-I	full	•	•	•	-	-	-
ICUMSA color index	full	•					
ADMI color	0 to 500	• 2)	•	-	-	-	-
Acid Wash color number	1 to 14	•					
EBC I, II, Wort, photometric, ASBC	0-60,120,50,25	•	•	-	-	•	-
Spectral transmission	T_{340} – T_{900}	• / 10nm	• / 10nm	• / 10nm	•	-	-
Photometric λ-scan	340nm..900nm	• / 1nm	• / 1nm	• / 1nm	-	-	-
Other functions / accessories							
Battery powered		-	-	-	-	-	o
User exchangeable cuvette compartment		•	-	-	-	•	-
Interface		USB/Lan	USB	RS232c	RS232c	USB	USB
CSV Data Export		•	•	•	•	•	-

Subject to technical modifications 1) Lovibond® is a registered trademark of THE Tintometer® LTD, UK 2) 0-1000 ADMI with V1.10 (o) option

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