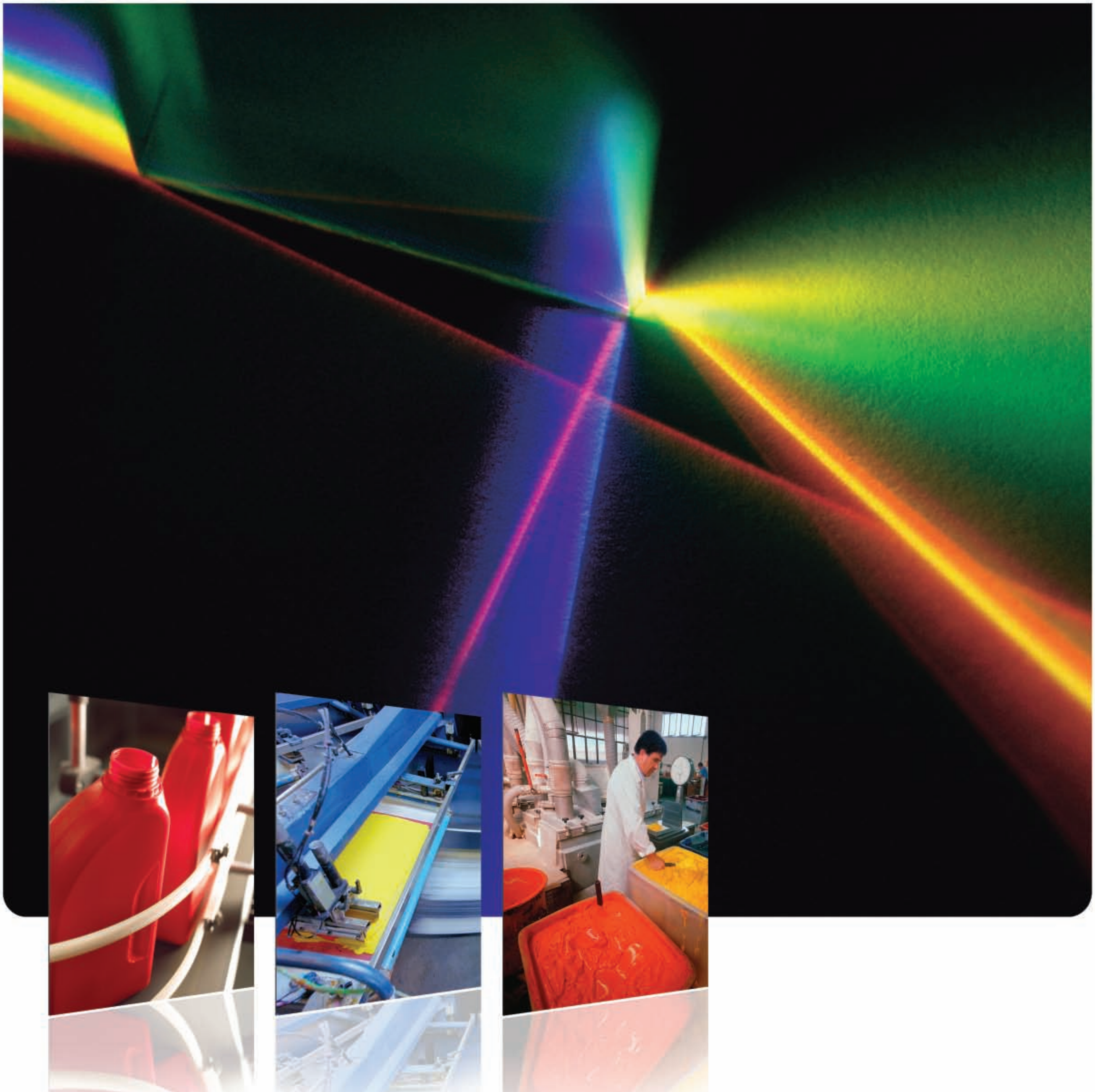

A Guide to Understanding Color Communication

x·rite

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Communicating Color

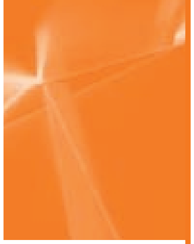
How would you describe the color of this rose? Would you say it's yellow, sort of lemon yellow or maybe a bright canary yellow?

Your perception and interpretation of color are highly subjective. Eye fatigue, age and other physiological factors can influence your color perception.

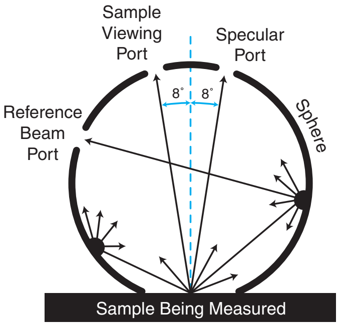
But even without such physical considerations, each observer interprets color based on personal references. Each person also verbally defines an object's color differently.

As a result, objectively communicating a particular color to someone without some type of standard is difficult. There also must be a way to compare one color to the next with accuracy.

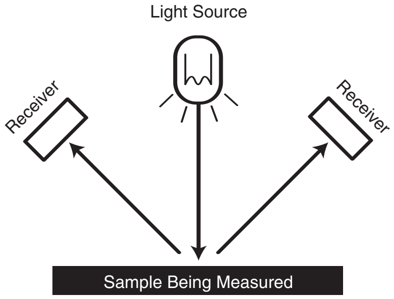
The solution is a measuring instrument that explicitly identifies a color. That is, an instrument that differentiates a color from all others and assigns it a numeric value.



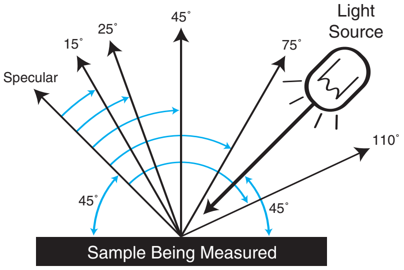
Ways to Measure Color



Spherical



0/45



Multi-angle

Today, the most commonly used instruments for measuring color are spectrophotometers.

Spectro technology measures reflected or transmitted light at many points on the visual spectrum, which results in a curve. Since the curve of each color is as unique as a signature or fingerprint, the curve is an excellent tool for identifying, specifying and matching color.

The following information can help you to understand which type of instrument is the best choice for specific applications.

Spherical

Spherically based instruments have played a major roll in formulation systems for nearly 50 years. Most are capable of including the “specular component” (gloss) while measuring. By opening a small trap door in the sphere, the “specular component” is excluded from the measurement. In most cases, databases for color formulation are more accurate when this component is a part of the measurement. Spheres are also the instrument of choice when the sample is textured, rough, or irregular or approaches the brilliance of a first-surface mirror. Textile manufacturers, makers of roofing tiles or acoustic ceiling materials would all likely select spheres as the right tool for the job.

0/45 (or 45/0)

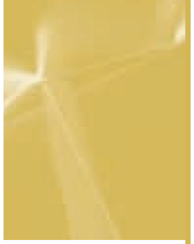
No instrument “sees” color more like the human eye than the 0/45. This simply is because a viewer does everything in his or her power to exclude the “specular component” (gloss) when judging color. When we look at pictures in a glossy magazine, we arrange ourselves so that the gloss does not reflect back to the eye. A 0/45 instrument, more effectively than any other, will remove gloss from the measurement and measure the appearance of the sample exactly as the human eye would see it.

Multi-Angle

In the past 10 or so years, car makers have experimented with special effect colors. They use special additives such as mica, pearlescent materials, ground up seashells, microscopically coated colored pigments and interference pigments to produce different colors at different angles of view. Large and expensive goniometers were traditionally used to measure these colors until X-Rite introduced a battery-powered, hand-held, multi-angle instrument. X-Rite portable multi-angle instruments are used by most auto makers and their colorant supply chain, worldwide.

Colorimeter

Colorimeters are not spectrophotometers. Colorimeters are tristimulus (three-filtered) devices that make use of red, green, and blue filters that emulate the response of the human eye to light and color. In some quality control applications, these tools represent the lowest cost answer. Colorimeters cannot compensate for metamerism (a shift in the appearance of a sample due to the light used to illuminate the surface). As colorimeters use a single type of light (such as incandescent or pulsed xenon) and because they do not record the spectral reflectance of the media, they cannot predict this shift. Spectrophotometers can compensate for this shift, making spectrophotometers a superior choice for accurate, repeatable color measurement.



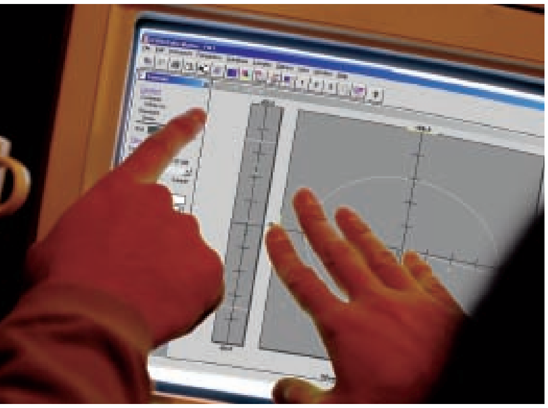
Integrated Color – Throughout the Supply Chain

Since color is a key element of a consumer's buying decisions, how do you handle color consistency and quality in a global environment? How do you keep in step with consumer color preferences while ensuring color options are available and easy to reproduce? The solution: X-Rite color measurement technology.

Accurate Color.
On Time. Every Time.

Whether you're working with coatings, plastics or textiles, X-Rite understands the challenges unique to your business. Because customer needs—not off-the-shelf products—drive the solutions we bring, our industry experts take the time to understand your business. The unique combination of X-Rite's technology, our vertically integrated manufacturing capabilities and the industry's largest global presence allows us to invent and adapt specific solutions for you, wherever you are.

When you streamline your workflow system, it can greatly reduce the complexity of your supply chain. With a digital supply chain solution for color control, you can shift color management responsibilities to your organization. This means you control color data workflow. The result: data flows faster, which provides the information needed to optimize choice of suppliers, and respond quickly to market pressures.



Controlling Color throughout the Process

X-Rite's product portfolio offers solutions which connect color accurately throughout the entire process. Our solutions save you money by reducing scrap, production downtime, off-color product shipments and rework. We simplify the process of managing color through-out your global supply chain, whether with multiple locations or at a single facility, helping you protect the quality of corporate brands.

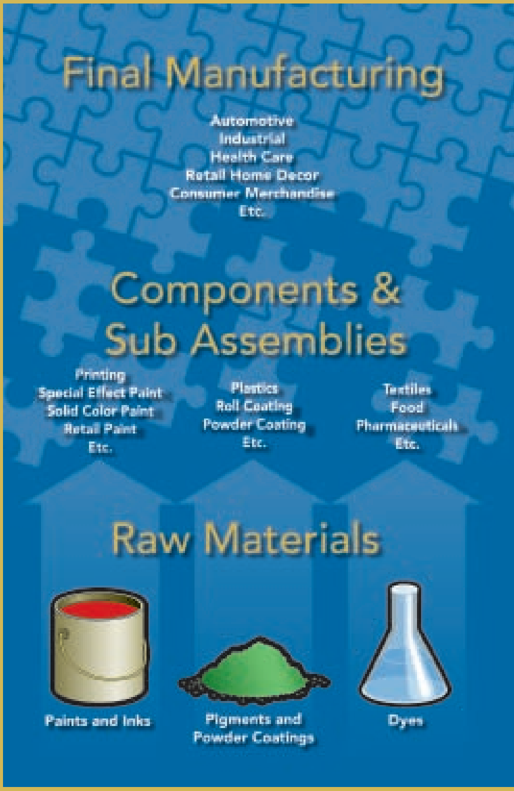
Offering a broad range of benchtop, portable or non-contact systems, X-Rite instruments can be found on the desktop, in retail settings, in laboratories or on production lines, all managing color reliably and accurately. Your total solution includes software that enhances instrument functionality by adding quality control, profiling functions, color matching, or color management packages. Complimented with our Macbeth Lighting offering and visual evaluation tools from Munsell Color, X-Rite offers the complete portfolio for all of your color needs.

X-Rite is a global leader in color measurement, management and communication solutions, and can help you get the right color, every time, from the earliest stages of production to final product shipment.

Calibrated, On-Screen Color

X-Rite offers the only color formulation and quality assurance software to use the International Color Consortium's (ICC) standard device profiles for on-screen color. This means that colors will be consistently displayed on different computers, so long as ICC profiles are used. Use X-Rite monitor optimizers and auto-scan densitometers for complete color calibration and control on computers, printers and scanners.

Integration



Applications

Spectrophotometry's applications are seemingly boundless. Color-matching measurements are made every day by those comparing a reproduced object to a reference point. Spectrophotometry-assisted color measurement can be useful in areas such as:

- Corporate logo standardization
- Color testing of inks
- Color control of paints
- Control of printed colors on packaging material and labels
- Color control of plastics and textiles throughout the development and manufacturing process
- Finished products like printed cans, clothing, shoes, automobile components, plastic components of all types

Attributes of Color

Each color has its own distinct appearance, based on three elements: hue, chroma and value (lightness). By describing a color using these three attributes, you can accurately identify a particular color and distinguish it from any other.

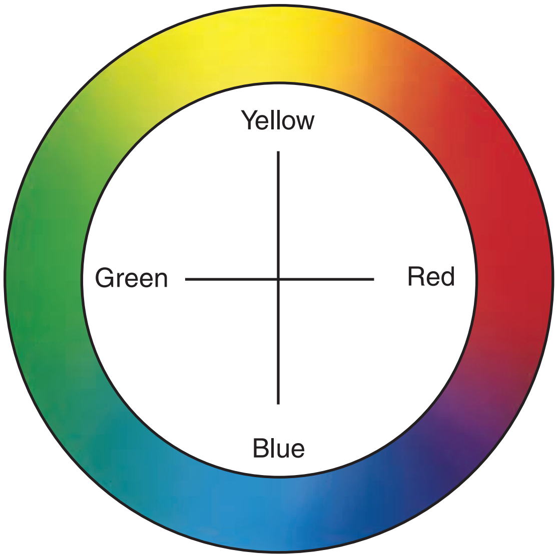


Figure 1: Hue

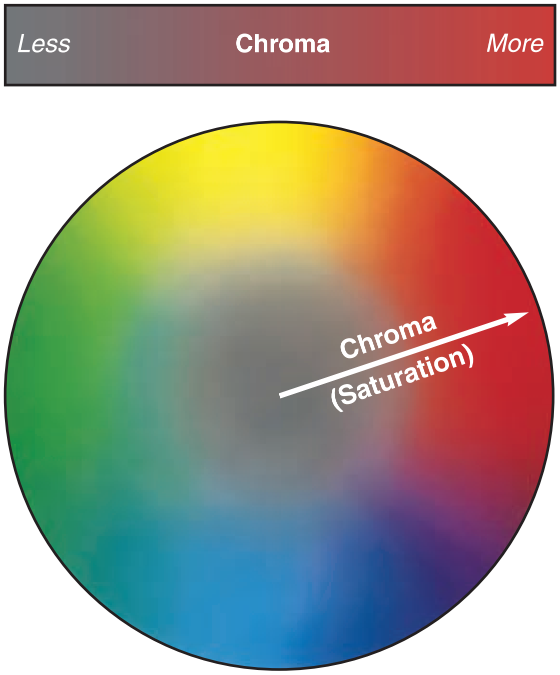


Figure 2: Chromaticity

Hue

When asked to identify the color of an object, you'll most likely speak first of its hue. Quite simply, hue is how we perceive an object's color — red, orange, green, blue, etc.

The color wheel in Figure 1 shows the continuum of color from one hue to the next. As the wheel illustrates, if you were to mix blue and green paints, you would get blue-green. Add yellow to green for yellow-green, and so on.

Chroma

Chroma describes the vividness or dullness of a color — in other words, how close the color is to either gray or the pure hue. For example, think of the appearance of a tomato and a radish. The red of the tomato is vivid, while the radish appears duller.

Figure 2 shows how chroma changes as we move from center to the perimeter. Colors in the center are gray (dull) and become more saturated (vivid) as they move toward the perimeter. Chroma also is known as saturation.

Lightness

The luminous intensity of a color — i.e., its degree of lightness — is called its value. Colors can be classified as light or dark when comparing their value.

For example, when a tomato and a radish are placed side by side, the red of the tomato appears to be much lighter. In contrast, the radish has a darker red value. In Figure 3, the value, or lightness, characteristic is represented on the vertical axis.

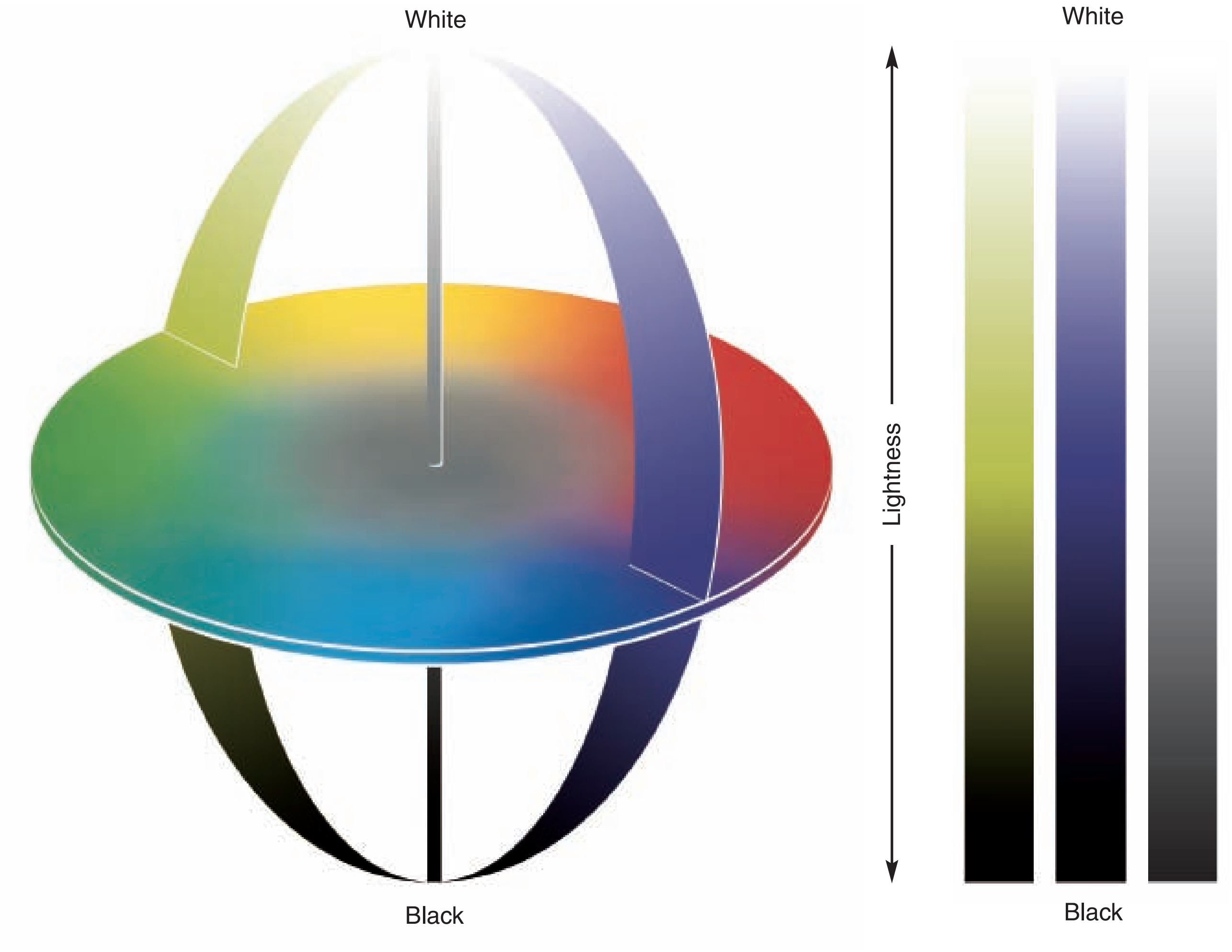
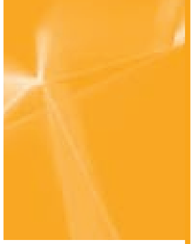


Figure 3: Three-dimensional color system depicting lightness



Scales for Measuring Color

Figure 4: Munsell Color Tree

The Munsell Scale

In 1905, artist Albert H. Munsell originated a color ordering system — or color scale — which is still used today. The Munsell System of Color Notation is significant from a historical perspective because it's based on human perception. Moreover, it was devised before instrumentation was available for measuring and specifying color. The Munsell System assigns numerical values to the three properties of color: hue, value and chroma. Adjacent color samples represent equal intervals of visual perception.

The model in Figure 4 depicts the Munsell Color Tree, which provides physical samples for judging visual color. Today's color systems rely on instruments that utilize mathematics to help us judge color.

Three things are necessary to see color:

- A light source (illuminant)
- An object (sample)
- An observer/processor

We as humans see color because our eyes process the interaction of light hitting an object. What if we replace our eyes with an instrument —can it see and record the same color differences that our eyes detect?

CIE Color Systems

The CIE, or Commission Internationale de l'Eclairage (translated as the International Commission on Illumination), is the body responsible for international recommendations for photometry and colorimetry. In 1931 the CIE standardized color order systems by specifying the light source (or illuminants), the observer and the methodology used to derive values for describing color.

The CIE Color Systems utilize three coordinates to locate a color in a color space. These color spaces include:

- CIE XYZ
- CIE L*a*b*
- CIE L*C*h°

To obtain these values, we must understand how they are calculated.

As stated earlier, our eyes need three things to see color: a light source, an object and an observer/processor. The same must be true for instruments to see color. Color measurement instruments receive color the same way our eyes do — by gathering and

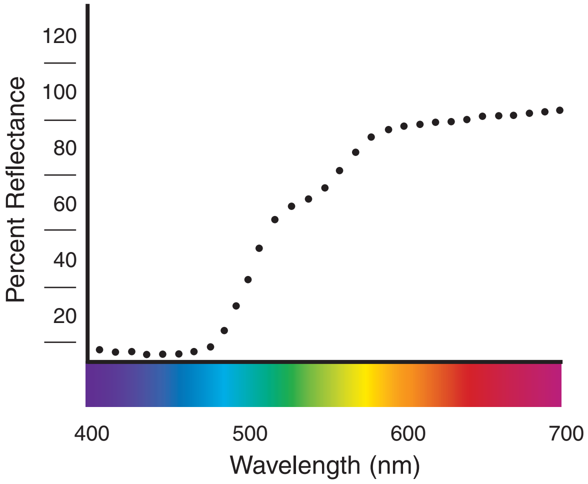


Figure 5: Spectral curve from a measured sample

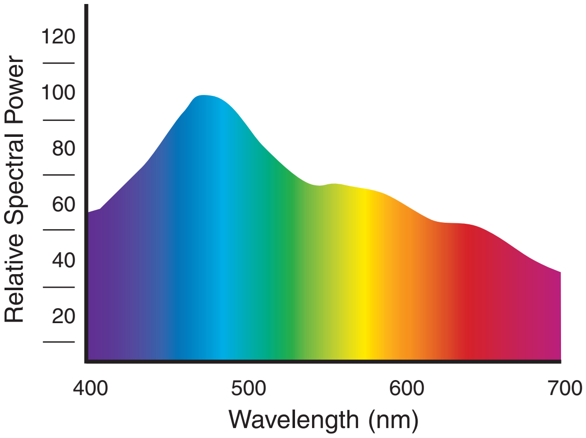


Figure 6: Daylight (Standard Illuminant D65/10˚)

filtering the wavelengths of light reflected from an object. The instrument perceives the reflected light wavelengths as numeric values. These values are recorded as points across the visible spectrum and are called spectral data. Spectral data is represented as a spectral curve. This curve is the color's fingerprint (Figure 5).

Once we obtain a color's reflectance curve, we can apply mathematics to map the color onto a color space.

To do this, we take the reflectance curve and multiply the data by a CIE standard illuminant. The illuminant is a graphical representation of the light source under which the samples are viewed. Each light source has a power distribution that affects how we see color. Examples of different illuminants are A — incandescent, D65 — daylight (Figure 6) and F2 — fluorescent.

We multiply the result of this calculation by the CIE standard observer. The CIE commissioned work in 1931 and 1964 to derive the concept of a standard observer, which is based on the average human response to wavelengths of light (Figure 7).

In short, the standard observer represents how an average person sees color across the visible spectrum. Once these values are calculated, we convert the data into the tristimulus values of XYZ (Figure 8). These values can now identify a color numerically.

A spectrophotometer measures spectral data – the amount of light energy reflected from an object at several intervals along the visible spectrum. The spectral data is shown as a spectral curve.

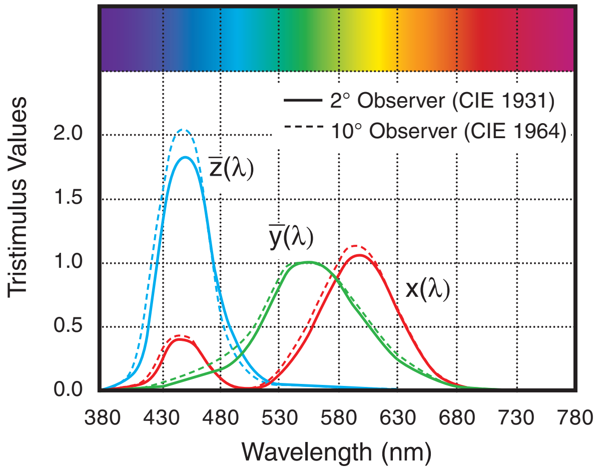


Figure 7: CIE 2° and 10° Standard Observers

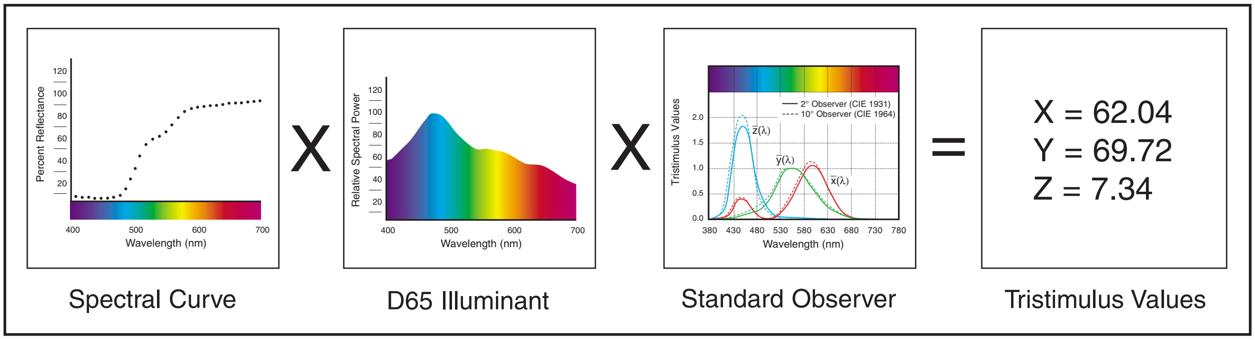


Figure 8: Tristimulus values

Chromaticity Values

Tristimulus values, unfortunately, have limited use as color specifications because they correlate poorly with visual attributes. While Y relates to value (lightness), X and Z do not correlate to hue and chroma.

As a result, when the 1931 CIE standard observer was established, the commission recommended using the chromaticity coordinates xyz. These coordinates are used to form the chromaticity diagram in Figure 9. The notation Yxy specifies colors by identifying value (Y) and the color as viewed in the chromaticity diagram (x,y).

As Figure 10 shows, hue is represented at all points around the perimeter of the chromaticity diagram. Chroma, or saturation, is represented by a movement from the central white (neutral) area out toward the diagram's perimeter, where 100% saturation equals pure hue.

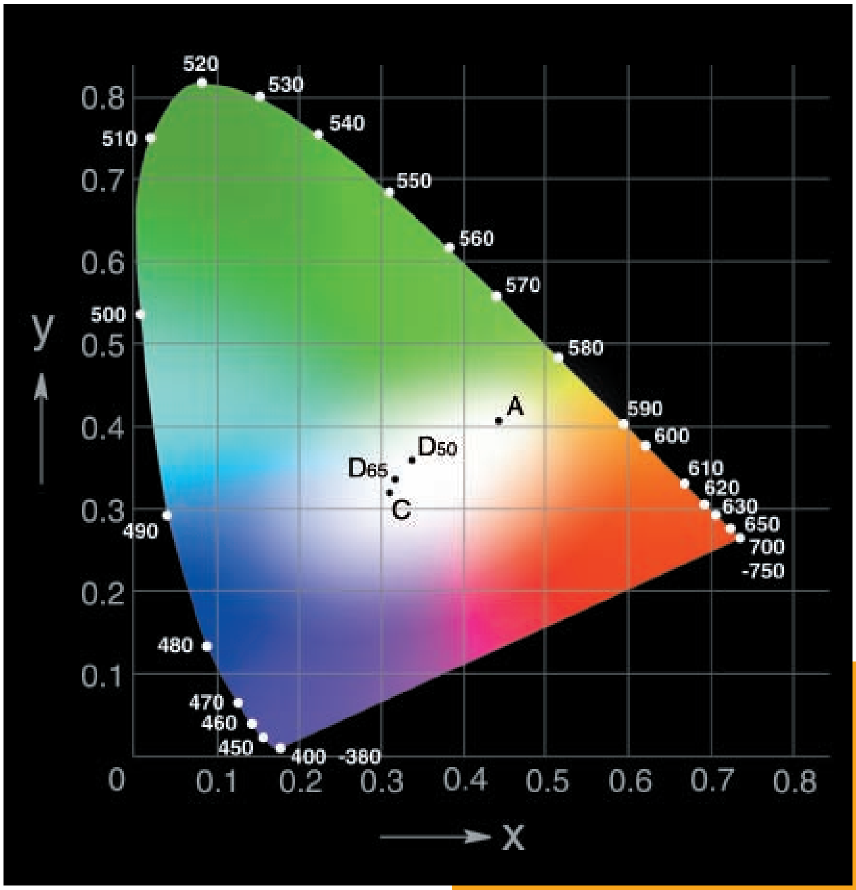


Figure 9: CIE 1931 (x, y) chromaticity diagram

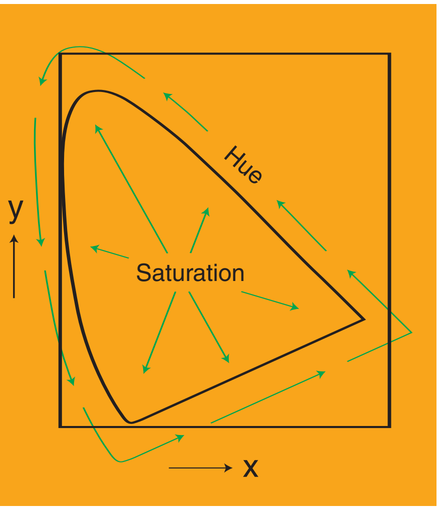
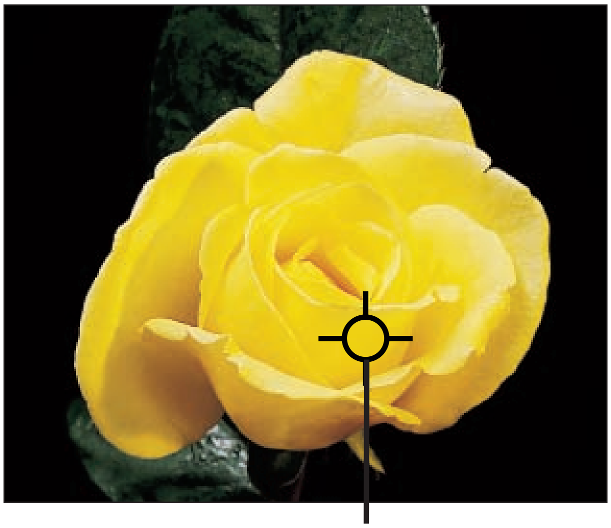


Figure 10: Chromaticity diagram

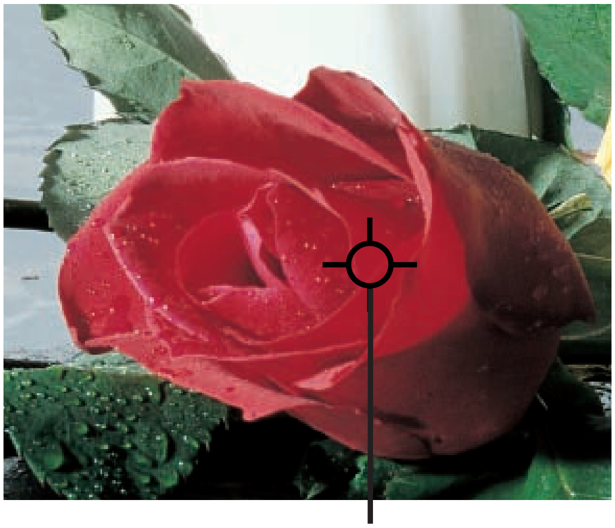
Expressing Colors Numerically

To overcome the limitations of chromaticity diagrams like Yxy, the CIE recommended two alternate, uniform color scales: CIE 1976 (L*a*b*) or CIELAB, and CIELCH (L*C*h°).

These color scales are based on the opponent-colors theory of color vision, which says that two colors cannot be both green and red at the same time, nor blue and yellow at the same time. As a result, single values can be used to describe the red/green and the yellow/blue attributes.



Flower A:
L = 52.99   a* = 8.82   b* = 54.53*



Flower B:
L = 29.00   a* = 52.48   b* = 22.23*

CIELAB (L*a*b*)

When a color is expressed in CIELAB, L* defines lightness, a* denotes the red/green value and b* the yellow/blue value.

Figures 11 and 12 (on page 13) show the color-plotting diagrams for L*a*b*. The a* axis runs from left to right. A color measurement movement in the +a direction depicts a shift toward red. Along the b* axis, +b movement represents a shift toward yellow. The center L* axis shows L = 0 (black or total absorption) at the bottom. At the center of this plane is neutral or gray.

To demonstrate how the L*a*b* values represent the specific colors of Flowers A and B, we've plotted their values on the CIELAB Color Chart in Figure 11.

The a* and b* values for Flowers A and B intersect at color spaces identified respectively as points A and B (see Figure 11). These points specify each flower's hue (color) and chroma (vividness/dullness). When their L* values (degree of lightness) are added in Figure 12, the final color of each flower is obtained.

CIELCH (L*C*h°)

While CIELAB uses Cartesian coordinates to calculate a color in a color space, CIELCH uses polar coordinates. This color expression can be derived from CIELAB. The L* defines lightness, C* specifies chroma and h° denotes hue angle, an angular measurement.

The L*C*h° expression offers an advantage over CIELAB in that it's very easy to relate to the earlier systems based on physical samples, like the Munsell Color Scale.

$L^* = 116\,(Y/Y_n)^{1/3} - 16$

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

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

$L^* = 116\,(Y/Y_n)^{1/3} - 16$

$C^* = (a^2 + b^2)^{1/2}$

$h° = \arctan\,(b^*/a^*)$

X_n, Y_n, Z_n, are values for a reference white for the illumination/observer used.

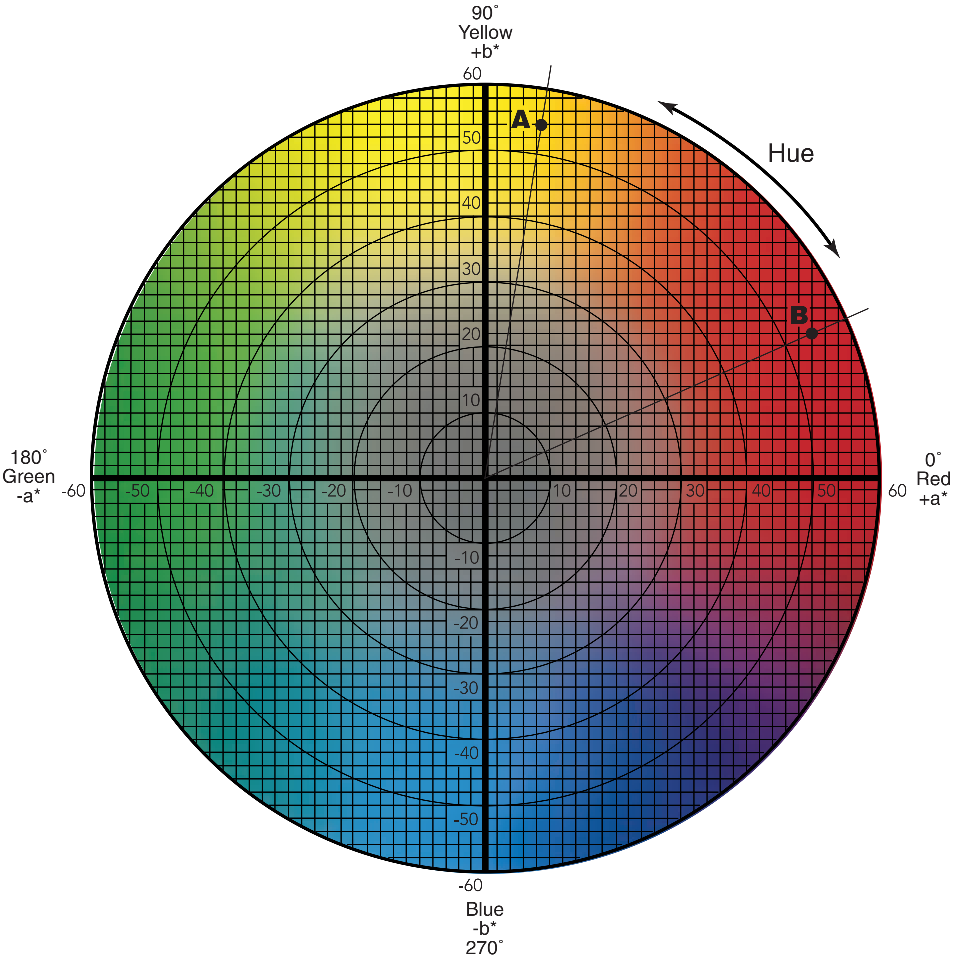


Figure 11: CIELAB color chart

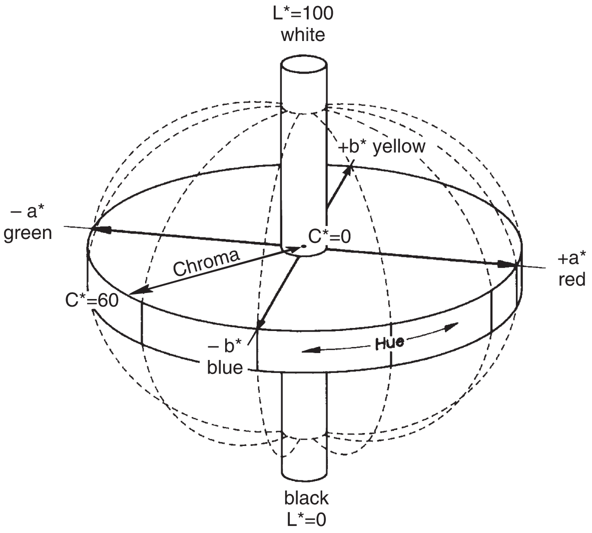
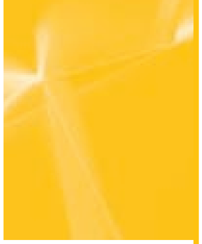


Figure 12: The L value is represented on the center axis. The a* and b* axes appear on the horizontal plane.*



Color Differences, Notation and Tolerancing

Delta CIELAB and CIELCH

Assessment of color is more than a numeric expression. Usually it's an assessment of the color difference (delta) from a known standard. CIELAB and CIELCH are used to compare the colors of two objects.

The expressions for these color differences are ΔL^* Δa^* Δb^* or DL* Da* Db*, and ΔL^* ΔC^* ΔH^* or DL* DC* DH* (Δ or D symbolizes "delta," which indicates difference).

Given ΔL^* Δa^* Δb^*, the total difference or distance on the CIELAB diagram can be stated as a single value, known as ΔE^*.

$$\Delta E^*_{ab} = [(\Delta L^2) + (\Delta a^2) + (\Delta b^2)]^{1/2}$$

Let's compare the color of Flower A to Flower C, pictured below. Separately, each would be classified as a yellow rose. But what is their relationship when set side by side? How do the colors differ?

Using the equation for ΔL^* Δa^* Δb^*, the color difference between Flower A and Flower C can be expressed as:

$$\Delta L^* = +11.10$$
$$\Delta a^* = -6.10$$
$$\Delta b^* = -5.25$$

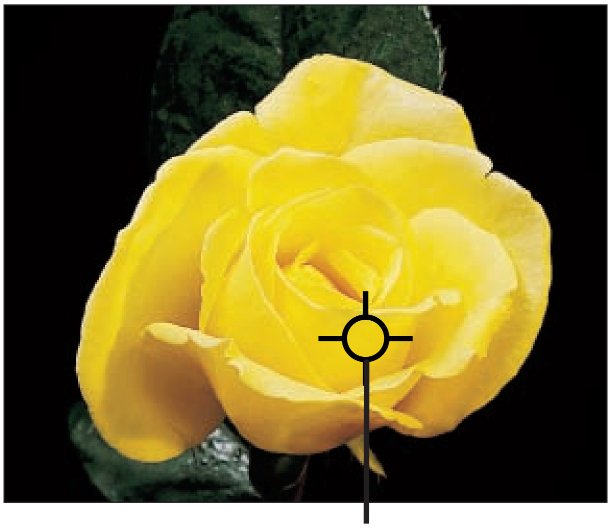
The total color difference can be expressed as $\Delta E^*=13.71$

The values for Flowers A and C are shown at the bottom of this page. On the a* axis, a reading of –6.10 indicates greener or less red. On the b* axis, a reading of –5.25 indicates bluer or less yellow. On the L* plane, the measurement difference of +11.10 shows that Flower C is lighter than Flower A.

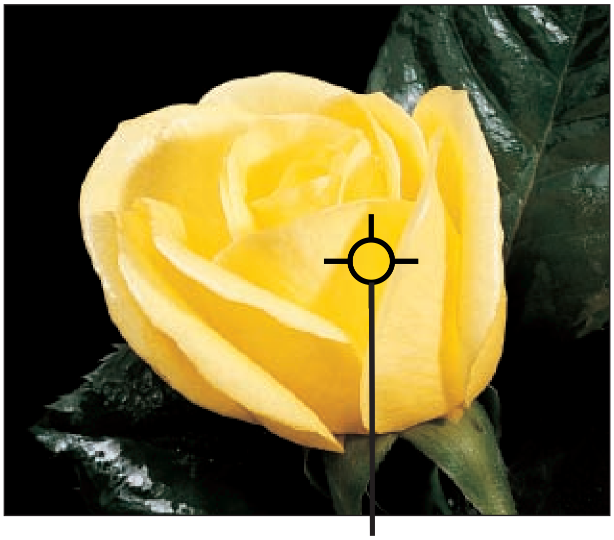
If the same two flowers were compared using CIELCH, the color differences would be expressed as:

$$\Delta L^* = +11.10$$
$$\Delta C^* = -5.88$$
$$\Delta H^* = 5.49$$

Referring again to the flowers shown below, the ΔC^* value of –5.88 indicates that Flower C is less chromatic, or less saturated. The ΔH^* value of 5.49 indicates that Flower C is greener in hue than Flower A. The L* and ΔL^* values are identical for CIELCH and CIELAB.



Flower A: $L^* = 52.99$ $a^* = 8.82$ $b^* = 54.53$



Flower C: $L^*=64.09$ $a^*=2.72$ $b^*=49.28$

Color difference of Flower C to A

$\Delta L^* = +11.10,\ \Delta a^* = -6.10,\ \Delta b^* = -5.25$

$\Delta E^*_{ab} = [(+11.1)^2 + (-6.1)^2 + (-5.25)^2]^{1/2}$

$\Delta E^*_{ab} = 13.71$

CIE Color Space Notation

ΔL* = difference in lightness/darkness value
+ = *lighter* **–** = *darker*

Δa* = difference on red/green axis
+ = *redder* **–** = *greener*

Δb* = difference on yellow/blue axis
+ = *yellower* **–** = *bluer*

ΔC* = difference in chroma
+ = *brighter* **–** = *duller*

ΔH* = difference in hue

ΔE* = total color difference value

Refer to Figure 11 on page 10.

Visual Color and Tolerancing

Poor color memory, eye fatigue, color blindness and viewing conditions can all affect the human eye's ability to distinguish color differences. In addition to those limitations, the eye does not detect differences in hue (red, yellow, green, blue, etc.), chroma (saturation) or lightness equally. In fact, the average observer will see hue differences first, chroma differences second and lightness differences last. Visual acceptability is best represented by an ellipsoid (Figure 13).

As a result, our tolerance for an acceptable color match consists of a three-dimensional boundary with varying limits for lightness, hue and chroma, and must agree with visual assessment. CIELAB and CIELCH can be used to create those boundaries. Additional tolerancing formulas, known as CMC and CIE94, produce ellipsoidal tolerances.

CIELAB Tolerancing

When tolerancing with CIELAB, you must choose a difference limit for ΔL* (lightness), Δa* (red/green), and Δb* (yellow/blue). These limits create a rectangular tolerance box around the standard (Figure 14).

When comparing this tolerance box with the visually accepted ellipsoid, some problems emerge. A box-shaped tolerance around the ellipsoid can give good numbers for unacceptable color. If the tolerance box is made small enough to fit within the ellipsoid, it is possible to get bad numbers for visually acceptable color (Figure 15).

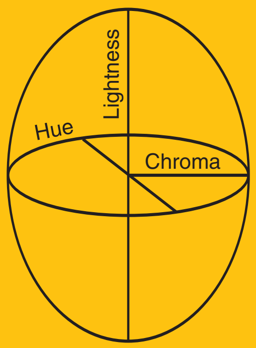


Figure 13: Tolerance ellipsoid

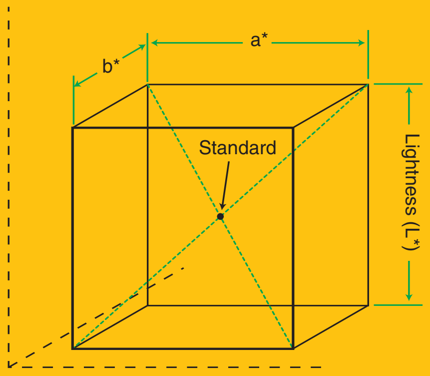


Figure 14: CIELAB tolerance box

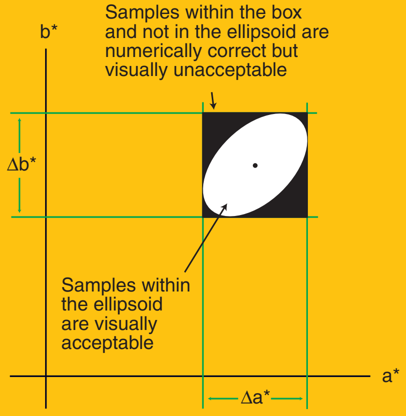


Figure 15: Numerically correct vs. visually acceptable

CIELCH Tolerancing

CIELCH users must choose a difference limit for ∆L* (lightness), ∆C* (chroma) and ∆H* (hue). This creates a wedge-shaped box around the standard. Since CIELCH is a polar-coordinate system, the tolerance box can be rotated in orientation to the hue angle (Figure 16).

When this tolerance is compared with the ellipsoid, we can see that it more closely matches human perception. This reduces the amount of disagreement between the observer and the instrumental values (Figure 17).

CMC Tolerancing

CMC is not a color space but rather a tolerancing system. CMC tolerancing is based on CIELCH and provides better agreement between visual assessment and measured color difference. CMC tolerancing was developed by the Colour Measurement Committee of the Society of Dyers and Colourists in Great Britain and became public domain in 1988.

The CMC calculation mathematically defines an ellipsoid around the standard color with semi-axis corresponding to hue, chroma and lightness. The ellipsoid represents the volume of acceptable color and automatically varies in size and shape depending on the position of the color in color space.

Figure 18 (on page 17) shows the variation of the ellipsoids throughout color space. The ellipsoids in the orange area of color space are longer and narrower than the broader and rounder ones in the green area. The size and shape of the ellipsoids also change as the color varies in chroma and/or lightness.

The CMC equation allows you to vary the overall size of the ellipsoid to better match what is visually acceptable. By varying the commercial factor (cf), the ellipsoid can be made as large or small as necessary to match visual assessment. The cf value is the tolerance, which means that if cf=1.0, then ∆E CMC less than 1.0 would pass, but more than 1.0 would fail (see Figure 19 on page 17).

Since the eye will generally accept larger differences in lightness (l) than in chroma (c), a default ratio for (l:c) is 2:1. A 2:1 ratio will allow twice as much difference in lightness as in chroma. The CMC equation allows this ratio to be adjusted to achieve better agreement with visual assessment (see Figure 20 on page 18).

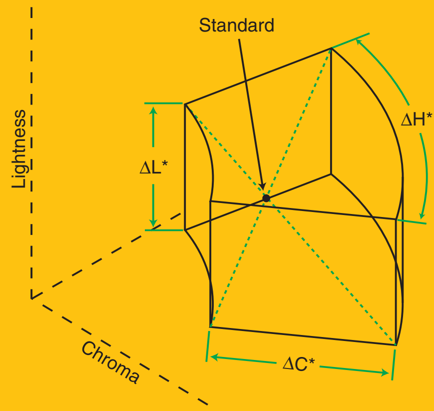


Figure 16: CIELCH tolerance wedge

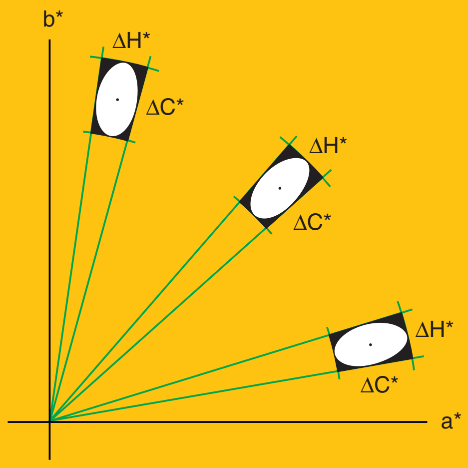


Figure 17: CIELCH tolerance ellipsoids

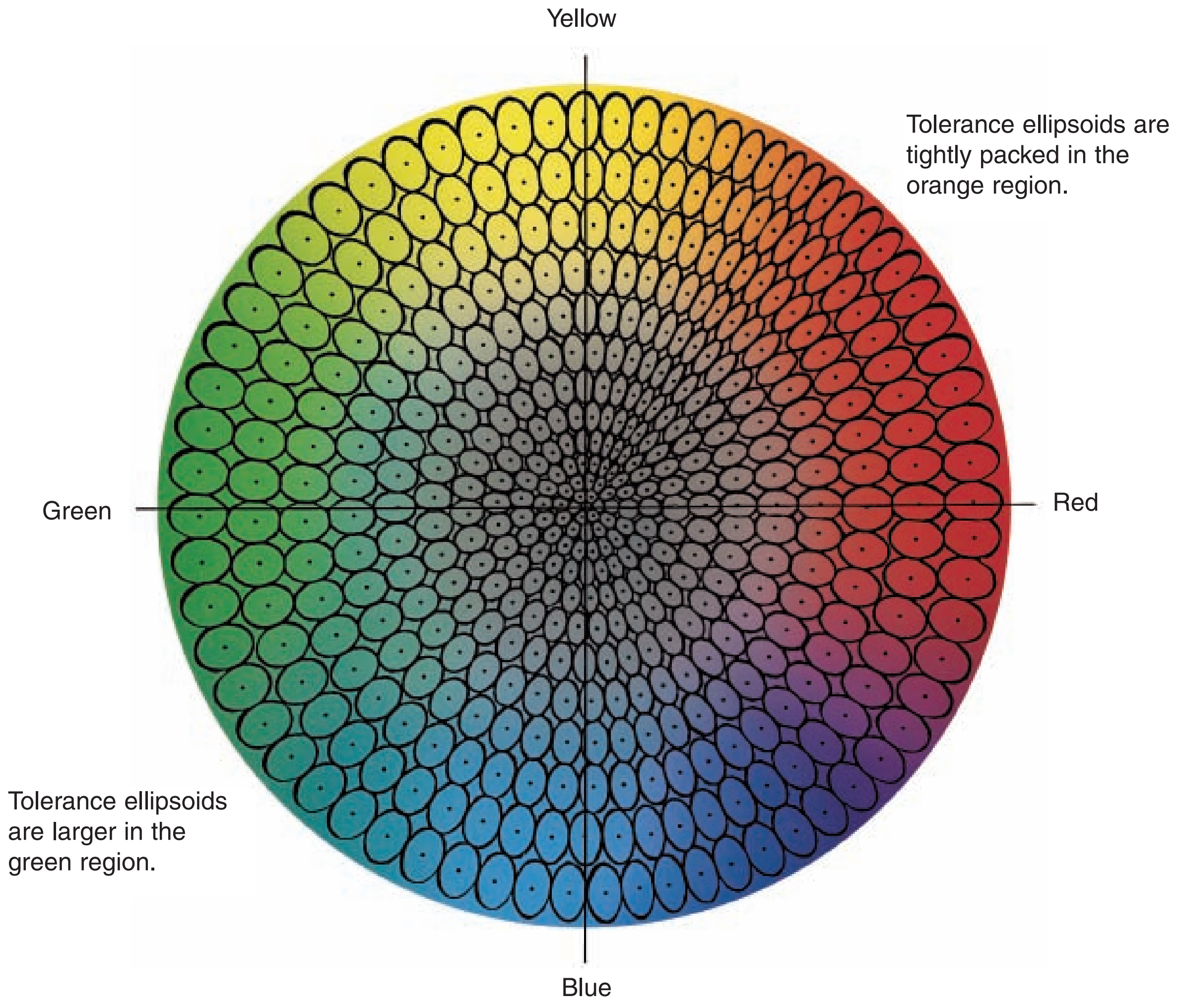


Figure 18: Tolerance ellipsoids in color space

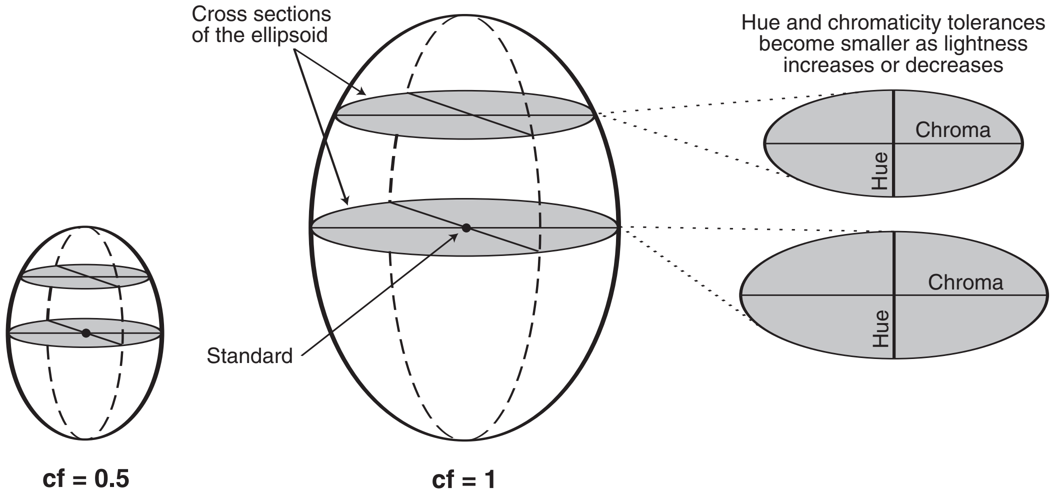


Figure 19: Commercial factor (cf) of tolerances

CIE94 Tolerancing

In 1994 the CIE released a new tolerance method called CIE94. Like CMC, the CIE94 tolerancing method also produces an ellipsoid. The user has control of the lightness (kL) to chroma (Kc) ratio, as well as the commercial factor (cf). These settings affect the size and shape of the ellipsoid in a manner similar to how the l:c and cf settings affect CMC.

However, while CMC is targeted for use in the textile industry, CIE94 is targeted for use in the paint and coatings industry. You should consider the type of surface being measured when choosing between these two tolerances. If the surface is textured or irregular, CMC may be the best fit. If the surface is smooth and regular, CIE94 may be the best choice.

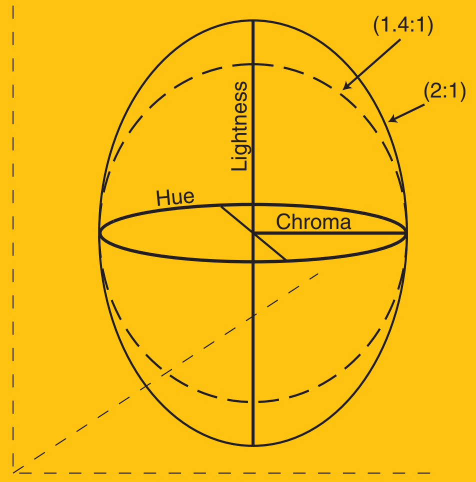


Figure 20: CMC tolerance ellipsoids

Visual Assessment vs. Instrumental

Though no color tolerancing system is perfect, the CMC and CIE94 equations best represent color differences as our eyes see them.

Tolerance Method	% Agreement with Visual
CIELAB	75%
CIELCH	85%
CMC or CIE94	95%

Choosing the Right Tolerance

When deciding which color difference calculation to use, consider the following five rules (Billmeyer 1970 and 1979):

1. Select a single method of calculation and use it consistently.

2. Always specify exactly how the calculations are made.

3. Never attempt to convert between color differences calculated by different equations through the use of average factors.

4. Use calculated color differences only as a first approximation in setting tolerances, until they can be confirmed by visual judgments.

5. Always remember that nobody accepts or rejects color because of numbers — it is the way it looks that counts.

Other Color Expressions

White and Yellow Indices

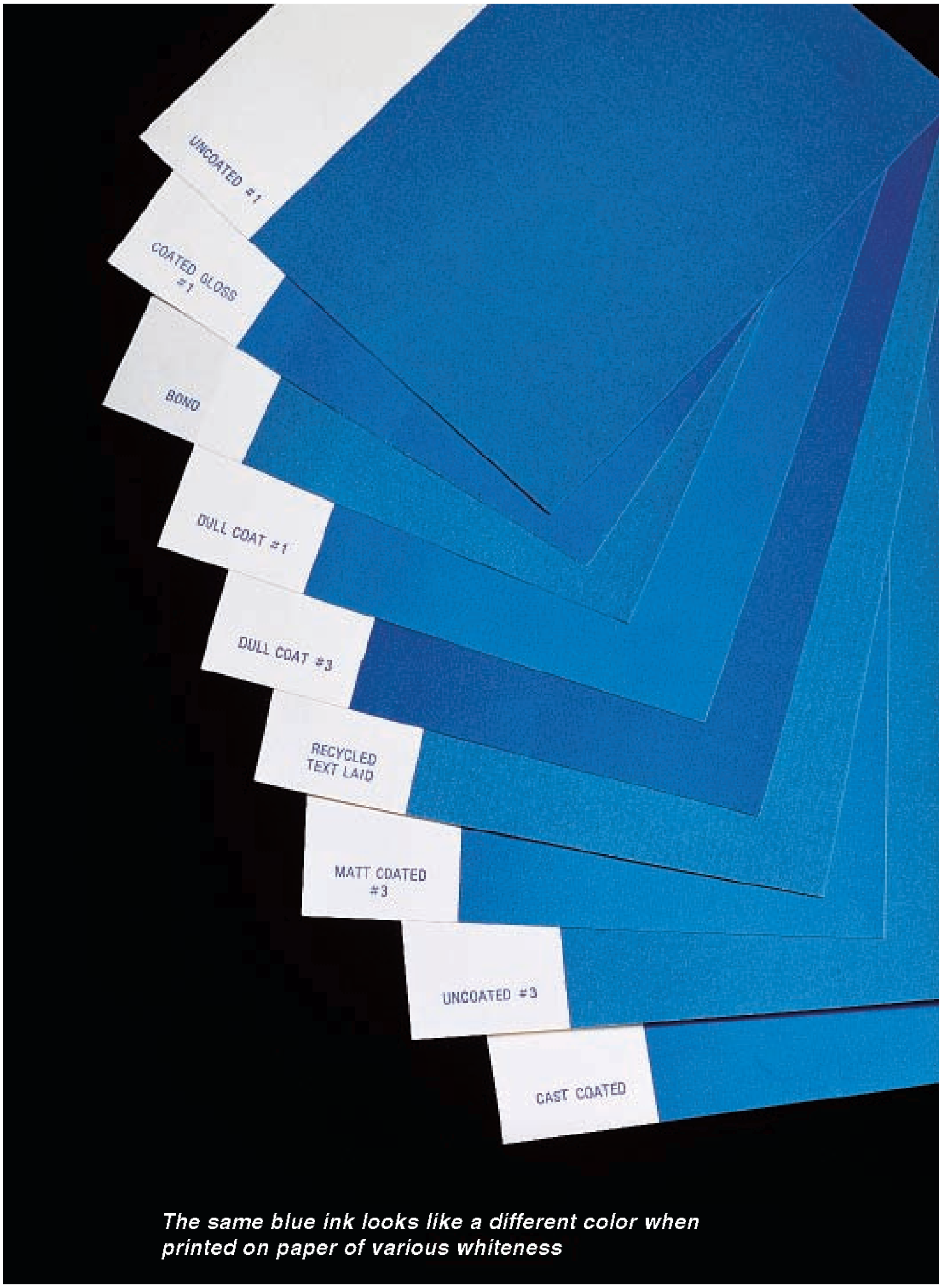
Certain industries, such as paint, textiles and paper manufacturing, evaluate their materials and products based on standards of whiteness. Typically, this whiteness index is a preference rating for how white a material should appear, be it photographic and printing paper or plastics.

In some instances, a manufacturer may want to judge the yellowness or tint of a material. This is done to determine how much that object's color departs from a preferred white toward a bluish tint.

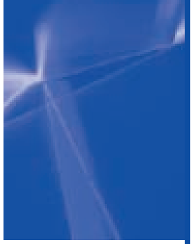
The effect of whiteness or yellowness can be significant, for example, when printing inks or dyes on paper. A blue ink printed on a highly-rated white stock will look different than the same ink printed on newsprint or another low-rated stock.

The American Standards Test Methods (ASTM) has defined whiteness and yellowness indices. The E313 whiteness index is used for measuring near-white, opaque materials such as paper, paint and plastic. In fact, this index can be used for any material whose color appears white.

The ASTM's E313 yellowness index is used to determine the degree to which a sample's color shifts away from an ideal white. The D1925 yellowness index is used for measuring plastics.



The same blue ink looks like a different color when printed on paper of various whiteness



Glossary

absolute white – In theory, a material that perfectly reflects all light energy at every visible wavelength. In practice, a solid white with known spectral reflectance data that is used as the “reference white” for all measurements of absolute reflectance. When calibrating a spectrophotometer, often a white ceramic plaque is measured and used as the absolute white reference.

absorb/absorption – Dissipation of the energy of electromagnetic waves into other forms (e.g., heat) as a result of its interaction with matter; a decrease in directional transmittance of incident radiation, resulting in a modification or conversion of the absorbed energy.

achromatic color – A neutral color that has no hue (white, gray or black).

additive primaries – Red, green and blue light. When all three additive primaries are combined at 100% intensity, white light is produced. When these three are combined at varying intensities, a gamut of different colors is produced. Combining two primaries at 100% produces a subtractive primary, either cyan, magenta or yellow:

100% red + 100% green = yellow
100% red + 100% blue = magenta
100% green + 100% blue = cyan

See *subtractive primaries*

appearance – An object’s or material’s manifestation through visual attributes such as size, shape, color, texture, glossiness, transparency, opacity, etc.

artificial daylight – Term loosely applied to light sources, frequently equipped with filters, that try to reproduce the color and spectral distribution of daylight. A more specific definition of the light source is preferred.

attribute – Distinguishing characteristic of a sensation, perception or mode of appearance. Colors are often described by their attributes of hue, chroma (or saturation) and lightness.

black – In theory, the complete absorption of incident light; the absence of any reflection. In practice, any color that is close to this ideal in a relative viewing situation — i.e., a color of very low saturation and very low luminance.

brightness – The dimension of color that refers to an achromatic scale, ranging from black to white. Also called lightness, luminous reflectance or transmittance (q.v.). Because of confusion with saturation, the use of this term should be discouraged.

c* – Abbreviation for chromaticity.

chroma/chromaticity – The intensity or saturation level of a particular hue, defined as the distance of departure of a chromatic color from the neutral (gray) color with the same value. In an additive color-mixing environment, imagine mixing a neutral gray and a vivid red with the same value. Starting with the neutral gray, add small amounts of red until the vivid red color is achieved. The resulting scale obtained would represent increasing chroma. The scale begins at zero for neutral colors, but has no arbitrary end. Munsell originally established 10 as the highest chroma for a vermilion pigment and related other pigments to it. Other pigments with higher chroma were noted, but the original scale remained. The chroma scale for normal reflecting materials may extend as high as 20, and for fluorescent materials it may be as high as 30.

chromatic – Perceived as having a hue — not white, gray or black.

chromaticity coordinates (CIE) – The ratios of each of the three tristimulus values X, Y and Z in relation to the sum of the three — designated as x, y and z respectively. They are sometimes referred to as the trichromatic coefficients. When written without subscripts, they are assumed to have been calculated for illuminant C and the 2° (1931) standard observer unless specified otherwise. If they have been obtained for other illuminants or observers, a subscript describing the observer or illuminant should be used. For example, x10 and y10 are chromaticity coordinates for the 10° observer and illuminant C.

chromaticity diagram (CIE) – A two-dimensional graph of the chromaticity coordinates (x as the abscissa and y as the ordinate), which shows the spectrum locus (chromaticity coordinates of monochromatic light, 380-770nm). It has many useful properties for comparing colors of both luminous and non-luminous materials.

CIE (Commission Internationale de l'Eclairage) – The International Commission on Illumination, the primary international organization concerned with color and color measurement.

CIE 1976 L*a*b* color space – A uniform color space utilizing an Adams-Nickerson cube root formula, adopted by the CIE in 1976 for use in the measurement of small color differences.

CIE 1976 L*u*v* color space – A uniform color space adopted in 1976. Appropriate for use in additive mixing of light (e.g., color TV).

CIE chromaticity coordinates – See *chromaticity coordinates (CIE).*

CIE chromaticity diagram – See *chromaticity diagram (CIE).*

CIE daylight illuminants – See *daylight illuminants (CIE).*

CIE luminosity function (y) – See *luminosity function (CIE).*
CIE standard illuminants – See *standard illuminants (CIE).*

CIE standard observer – See *standard observer (CIE).*

CIE tristimulus values – See *tristimulus values (CIE).*

CIELAB (or CIE L*a*b*, CIE Lab) – Color space in which values L*, a* and b* are plotted using Cartesian coordinate system. Equal distances in the space approximately represent equal color differences. Value L* represents lightness; value a* represents the red/green axis; and value b* represents the yellow/blue axis. CIELAB is a popular color space for use in measuring reflective and transmissive objects.

CMC (Colour Measurement Committee of the Society of Dyes and Colourists of Great Britain) – Organization that developed and published in 1988 a more logical, ellipse-based equation based on L*C*h° color space for computing DE (see *delta E**) values as an alternative to the rectangular coordinates of the CIELAB color space.

color – One aspect of appearance; a stimulus based on visual response to light, consisting of the three dimensions of hue, saturation and lightness.

color attribute – A three-dimensional characteristic of the appearance of an object. One dimension usually defines the lightness, the other two together define the chromaticity.

color difference – The magnitude and character of the difference between two colors under specified conditions.

color-matching functions – Relative amounts of three additive primaries required to match each wavelength of light. The term is generally used to refer to the CIE standard observer color-matching functions.

color measurement – Physical measurement of light radiated, transmitted or reflected by a specimen under specified condition and mathematically transformed into standardized colorimetric terms. These terms can be correlated with visual evaluations of colors relative to one another.

color model – A color-measurement scale or system that numerically specifies the perceived attributes of color. Used in computer graphics applications and by color measurement instruments.

color order systems – Systems used to describe an orderly three-dimensional arrangement of colors. Three bases can be used for ordering colors: 1) an appearance basis (i.e., a psychological basis) in terms of hue, saturation and lightness; an example is the Munsell System; 2) an orderly additive color mixture basis (i.e., a psychophysical basis); examples are the CIE System and the Ostwald System; and 3) an orderly subtractive color mixture basis; an example is the Plochere Color System based on an orderly mixture of inks.

color space – Three-dimensional solid enclosing all possible colors. The dimensions may be described in various geometries, giving rise to various spacings within the solid.

color specification – Tristimulus values, chromaticity coordinates and luminance value, or other color-scale values, used to designate a color numerically in a specified color system.

color temperature – A measurement of the color of light radiated by a black body while it is being heated. This measurement is expressed in terms of absolute scale, or degrees Kelvin. Lower Kelvin temperatures such as 2400K are red; higher temperatures such as 9300K are blue. Neutral temperature is white, at 6504K.

color wheel – The visible spectrum's continuum of colors arranged in a circle, where complementary colors such as red and green are located directly across from each other.

colorants – Materials used to create colors — dyes, pigments, toners, waxes, phosphors.

colorimeter – An optical measurement instrument that responds to color in a manner similar to the human eye — by filtering reflected light into its dominant regions of red, green and blue.

colorimetric – Of, or relating to, values giving the amounts of three colored lights or receptors — red, green and blue.

colorist – A person skilled in the art of color matching (colorant formulation) and knowledgeable concerning the behavior of colorants in a particular material; a tinter (q.v.) (in the American usage) or a shader. The word “colorist” is of European origin.

complements – Two colors that create neutral gray when combined. On a color wheel, complements are directly opposite from each other: blue/yellow, red/green and so on.

contrast – The level of variation between light and dark areas in an image.

D65 – The CIE standard illuminant that represents a color temperature of 6504K. This is the color temperature most widely used in graphic arts industry viewing booths. See *Kelvin (K)*.

daylight illuminants (CIE) – Series of illuminant spectral power distribution curves based on measurements of natural daylight and recommended by the CIE in 1965. Values are defined for the wavelength region 300 to 830nm. They are described in terms of the correlated color temperature. The most important is D65 because of the closeness of its correlated color temperature to that of illuminant C, 6774K. D75 bluer than D65 and D55 yellower than D65 are also used.

delta (D or ∆) – A symbol used to indicate deviation or difference.

delta E*, delta e* – The total color difference computed with a color difference equation (ΔE_{ab} or ΔE_{cmc}). In color tolerancing, the symbol DE is often used to express Delta Error.

dye – A soluble colorant — as opposed to pigment, which is insoluble.

dynamic range – An instrument’s range of measurable values, from the lowest amount it can detect to the highest amount it can handle.

electromagnetic spectrum – The massive band of electromagnetic waves that pass through the air in different sizes, as measured by wavelength. Different wavelengths have different properties, but most are invisible — and some completely undetectable — to human beings. Only wavelengths that are between 380 and 720 nanometers are visible, producing light. Waves outside the visible spectrum include gamma rays, x-rays, microwaves and radio waves.

emissive object – An object that emits light. Emission is usually caused by a chemical reaction, such as the burning gasses of the sun or the heated filament of a light bulb.

fluorescent lamp – A glass tube filled with mercury gas and coated on its inner surface with phosphors. When the gas is charged with an electrical current, radiation is produced. This, in turn, energizes the phosphors, causing them to glow.

gloss – An additional parameter to consider when determining a color standard, along with hue, value, chroma, the texture of a material and whether the material has metallic or pearlescent qualities. Gloss is an additional tolerance that may be specified in the Munsell Color Tolerance Set. The general rule for evaluating the gloss of a color sample is the higher the gloss unit, the darker the color sample will appear. Conversely, the lower the gloss unit, the lighter a sample will appear.

Gloss is measured in gloss units, which use the angle of measurement and the gloss value (e.g. 60˚ gloss = 29.8). A 60˚ geometry is recommended by the American Society for Testing and Materials (ASTM) D523 standard for the general evaluation of gloss.

grayscale – An achromatic scale ranging from black through a series of successively lighter grays to white. Such a series may be made up of steps that appear to be equally distant from one another (such as the Munsell Value Scale), or it may be arranged according to some other criteria such as a geometric progression based on lightness. Such scales may be used to describe the relative amount of difference between two similar colors.

hue – 1) The first element in the color-order system, defined as the attribute by which we distinguish red from green, blue from yellow, etc. Munsell defined five principal hues (red, yellow, green, blue and purple) and five intermediate hues (yellow-red, green-yellow, blue-green, purple-blue and red-purple. These 10 hues (represented by their corresponding initials R, YR, Y, GY, G, BG, B, PB, P and RP) are equally spaced around a circle divided into 100 equal visual steps, with the zero point located at the beginning of the red sector. Adjacent colors in this circle may be mixed to obtain continuous variation from one hue to another. Colors defined around the hue circle are known as chromatic colors. 2) The attribute of color by means of which a color is perceived to be red, yellow, green, blue, purple, etc. White, black and gray possess no hue.

illuminant – Mathematical description of the relative spectral power distribution of a real or imaginary light source — i.e., the relative energy emitted by a source at each wavelength in its emission spectrum. Often used synonymously with “light source” or “lamp,” though such usage is not recommended.

illuminant A (CIE) – Incandescent illumination, yellow-orange in color, with a correlated color temperature of 2856K. It is defined in the wavelength range of 380 to 770nm.

illuminant C (CIE) – Tungsten illumination that simulates average daylight, bluish in color, with a correlated color temperature of 6774K.

illuminants D (CIE) – Daylight illuminants, defined from 300 to 830nm (the UV portion 300 to 380nm being necessary to correctly describe colors that contain fluorescent dyes or pigments). They are designated as D, with a subscript to describe the correlated color temperature; D65 is the most commonly used, having a correlated color temperature of 6504K, close to that of illuminant C. They are based on actual measurements of the spectral distribution of daylight.

integrating sphere – A sphere manufactured or coated with a highly reflective material that diffuses light within it.

Kelvin (K) – Unit of measurement for color temperature. The Kelvin scale starts from absolute zero, which is -273˚ Celsius.

light – 1) Electromagnetic radiation of which a human observer is aware through the visual sensations that arise from the stimulation of the retina of the eye. This portion of the spectrum includes wavelengths from about 380 to 770nm. Thus, to speak of ultraviolet light is incorrect because the human observer cannot see radiant energy in the ultraviolet region. 2) Adjective meaning high reflectance, transmittance or level of illumination as contrasted to dark, or low level of intensity.

light source – An object that emits light or radiant energy to which the human eye is sensitive. The emission of a light source can be described by the relative amount of energy emitted at each wavelength in the visible spectrum, thus defining the source as an illuminant. The emission also may be described in terms of its correlated color temperature.

lightness – Perception by which white objects are distinguished from gray, and light-colored objects from dark-colored.

luminosity function (y) (CIE) – A plot of the relative magnitude of the visual response as a function of wavelength from about 380 to 780nm, adopted by CIE in 1924.

metamerism – A phenomenon exhibited by a pair of colors that match under one or more sets of illuminants (be they real or calculated), but not under all illuminants.

Munsell Color System – The color identification of a specimen by its Munsell hue, value and chroma as visually estimated by comparison with the Munsell Book of Color.

nanometer (nm) – Unit of length equal to 10-9 meter (a.k.a. one billionth of a meter, or a milli-micron).

observer – The human viewer who receives a stimulus and experiences a sensation from it. In vision, the stimulus is a visual one and the sensation is an appearance.

observer, standard – See *standard observer.*

radiant energy – A form of energy consisting of the electromagnetic spectrum, which travels at 299,792 kilometers/second (186,206 miles/second) through a vacuum, and more slowly in denser media (air, water, glass, etc.). The nature of radiant energy is described by its wavelength or frequency, although it also behaves as distinct quanta (“corpuscular theory”). The various types of energy may be transformed into other forms of energy (electrical, chemical, mechanical, atomic, thermal, radiant), but the energy itself cannot be destroyed.

reflectance – The ratio of the intensity of reflected radiant flux to that of incident flux. In popular usage, it is considered the ratio of the intensity of reflected radiant energy to that reflected from a defined reference standard.

reflectance, specular – See *specular reflectance.*

reflectance, total – See *total reflectance.*

saturation – The attribute of color perception that expresses the amount of departure from a gray of the same lightness. All grays have zero saturation (ASTM). See *chroma/chromaticity.*

scattering – Diffusion or redirection of radiant energy encountering particles of different refractive index. Scattering occurs at any such interface, at the surface, or inside a medium containing particles.

spectral power distribution curve – Intensity of radiant energy as a function of wavelength, generally given in relative power terms.

spectrophotometer – Photometric device that measures spectral transmittance, spectral reflectance or relative spectral emittance.

spectrophotometric curve – A curve measured on a spectrophotometer; a graph with relative reflectance or transmittance (or absorption) as the ordinate, plotted with wavelength or frequency as the abscissa.

spectrum – Spatial arrangement of components of radiant energy in order of their wavelengths, wave number or frequency.

specular gloss – Relative luminous fractional reflectance from a surface in the mirror or specular direction. It is sometimes measured at 60˚ relative to a perfect mirror.

specular reflectance – Reflectance of a beam of radiant energy at an angle equal but opposite to the incident angle; the mirror-like reflectance. The magnitude of the specular reflectance on glossy materials depends on the angle and the difference in refractive indices between two media at a surface. The magnitude may be calculated from Fresnel’s Law.

specular reflectance excluded (SCE) – Measurement of reflectance made in such a way that the specular reflectance is excluded from the measurement; diffuse reflectance. The exclusion may be accomplished by using 0˚ (perpendicular) incidence on the samples. This then reflects the specular component of the reflectance back into the instrument by use of black absorbers or light traps at the specular angle when the incident angle is not perpendicular, or in directional measurements by measuring at an angle different from the specular angle.

specular reflectance included (SCI) – Measurement of the total reflectance from a surface, including the diffuse and specular reflectances.

standard – A reference against which instrumental measurements are made.

standard illuminants (CIE) – Known spectral data established by the CIE for four different types of light sources. When using tristimulus data to describe a color, the illuminant must also be defined. These standard illuminants are used in place of actual measurements of the light source.

standard observer (CIE) – 1) A hypothetical observer having the tristimulus color-mixture data recommended in 1931 by the CIE for a 2˚ viewing angle. A supplementary observer for a larger angle of 10˚ was adopted in 1964. 2) The spectral response characteristics of the average observer defined by the CIE. Two such sets of data are defined, the 1931 data for the 2˚ visual field (distance viewing) and the 1964 data for the annular 10˚ visual field (approximately arm's length viewing). By custom, the assumption is made that if the observer is not specified, the tristimulus data has been calculated for the 1931, or 2˚ field observer. The use of the 1964 data should be specified.

subtractive primaries – Cyan, magenta and yellow. Theoretically, when all three subtractive primaries are combined at 100% on white paper, black is produced. When these are combined at varying intensities, a gamut of different colors is produced. Combining two primaries at 100% produces an additive primary, either red, green or blue:

100% cyan + 100% magenta = blue
100% cyan + 100% yellow = green
100% magenta + 100% yellow = red

tint – 1) *verb:* To mix white pigment with absorbing (generally chromatic) colorants. 2) *noun:* The color produced by mixing white pigment with absorbing (generally chromatic) colorants. The resulting mixture is lighter and less saturated than the color without the white added.

total reflectance – Reflectance of radiant flux reflected at all angles from the surface, thus including both diffuse and specular reflectances.

transparent – Describes a material that transmits light without diffusion or scattering.

tristimulus – Of, or consisting of, three stimuli; generally used to describe components of additive mixture required to evoke a particular color sensation.

tristimulus colorimeter – An instrument that measures tristimulus values and converts them to chromaticity components of color.

tristimulus values (CIE) – Percentages of the components in a three-color additive mixture necessary to match a color; in the CIE system, they are designated as X, Y and Z. The illuminant and standard observer color-matching functions used must be designated; if they are not, the assumption is made that the values are for the 1931 observer (2˚ field) and illuminant C. The values obtained depend on the method of integration used, the relationship of the nature of the sample and the instrument design used to measure the reflectance or transmittance. Tristimulus values are not, therefore, absolute values characteristic of a sample, but relative values dependent on the method used to obtain them. Approximations of CIE tristimulus values may be obtained from measurements made on a tristimulus colorimeter that gives measurements generally normalized to 100. These must then be normalized to equivalent CIE values. The filter measurements should be properly designated as R, G and B instead of X, Y and Z.

value – Indicates the degree of lightness or darkness of a color in relation to a neutral gray scale. The scale of value (or V, in the Munsell system of color notation) ranges from 0 for pure black to 10 for pure white. The value scale is neutral or without hue.

X – 1) One of the three CIE tristimulus values; the red primary. 2) Spectral color-matching functions of the CIE standard observer used for calculating the X tristimulus value. 3) One of the CIE chromaticity coordinates calculated as the fraction of the sum of the three tristimulus values attributable to the X value.

Y – 1) One of the three CIE tristimulus values, equal to the luminous reflectance or transmittance; the green primary. 2) Spectral color-matching function of the CIE standard observer used for calculating Y tristimulus value. 3) One of the CIE chromaticity coordinates calculated as the fraction of the sum of the three tristimulus values, attributable to the Y value.

Z – 1) One of the three CIE tristimulus values; the blue primary. 2) Spectral color-matching function of the CIE standard observer used for calculating the Z tristimulus value. 3) One of the CIE chromaticity coordinates calculated as the fraction of the sum of the three tristimulus values attributable to the Z primary.

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