A Guide to Understanding Color Communication Part 2

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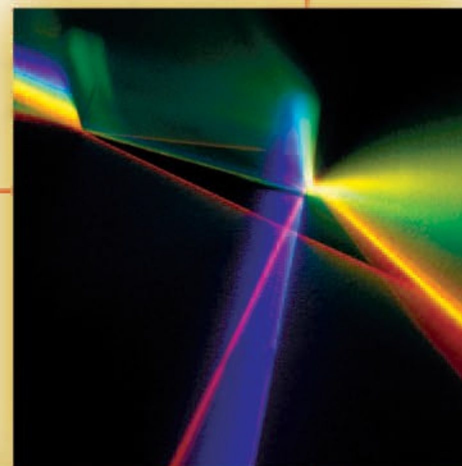

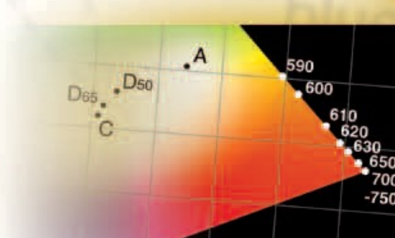

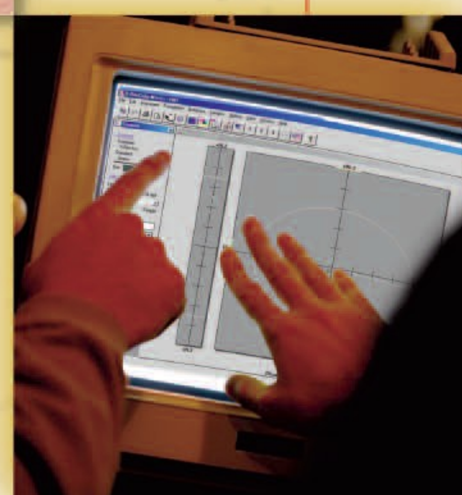

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Attributes of Color

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.

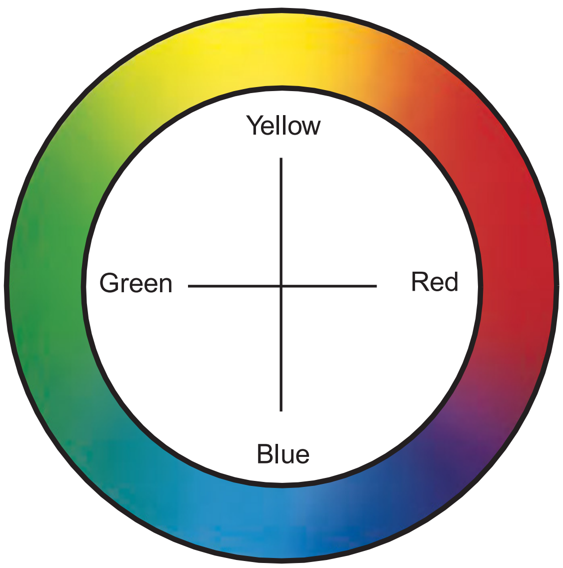


Figure 1: Hue

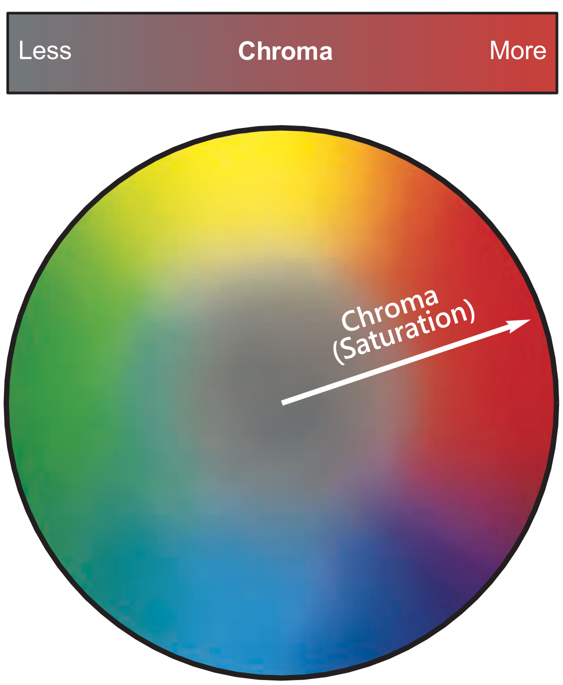


Figure 2: Chromaticity

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.

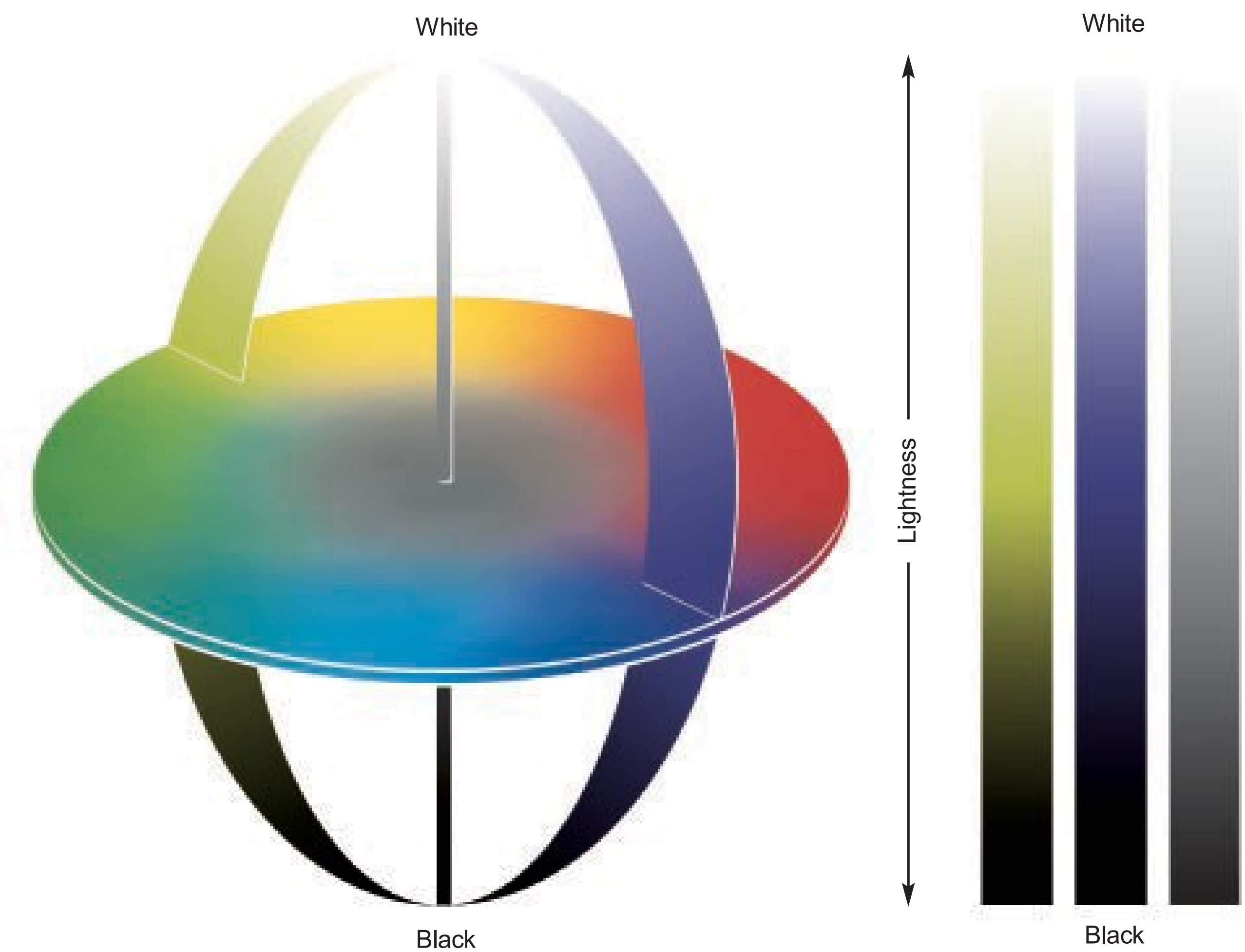


Figure 3: Three-dimensional color system depicting lightness

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

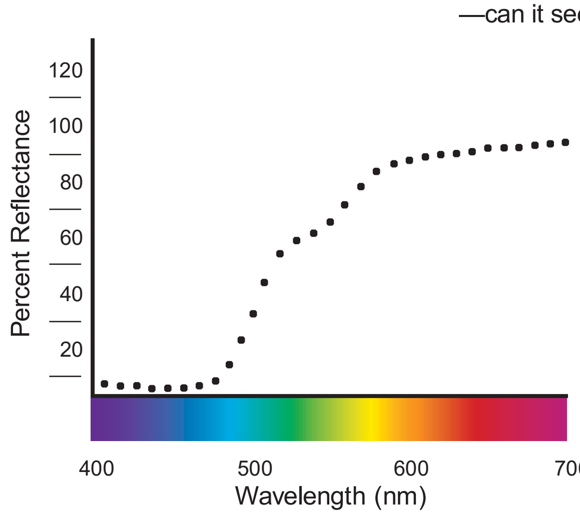


Figure 5: Spectral curve from a measured sample

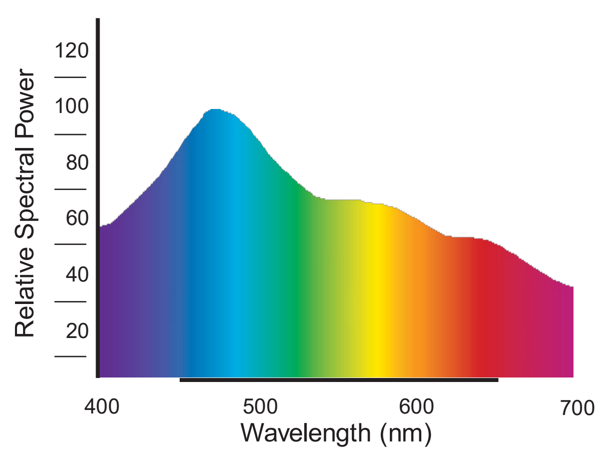


Figure 6: Daylight (Standard Illuminant D65/10˚)

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.

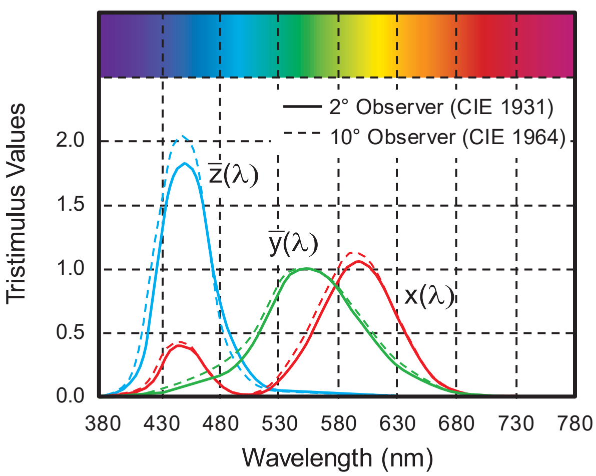


Figure 7: CIE 2° and 10° Standard Observers

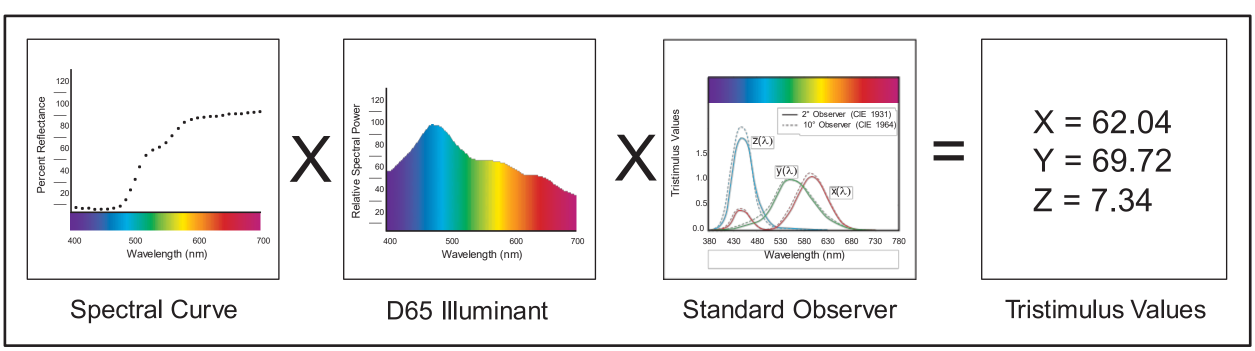


Figure 8: Tristimulus values

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.

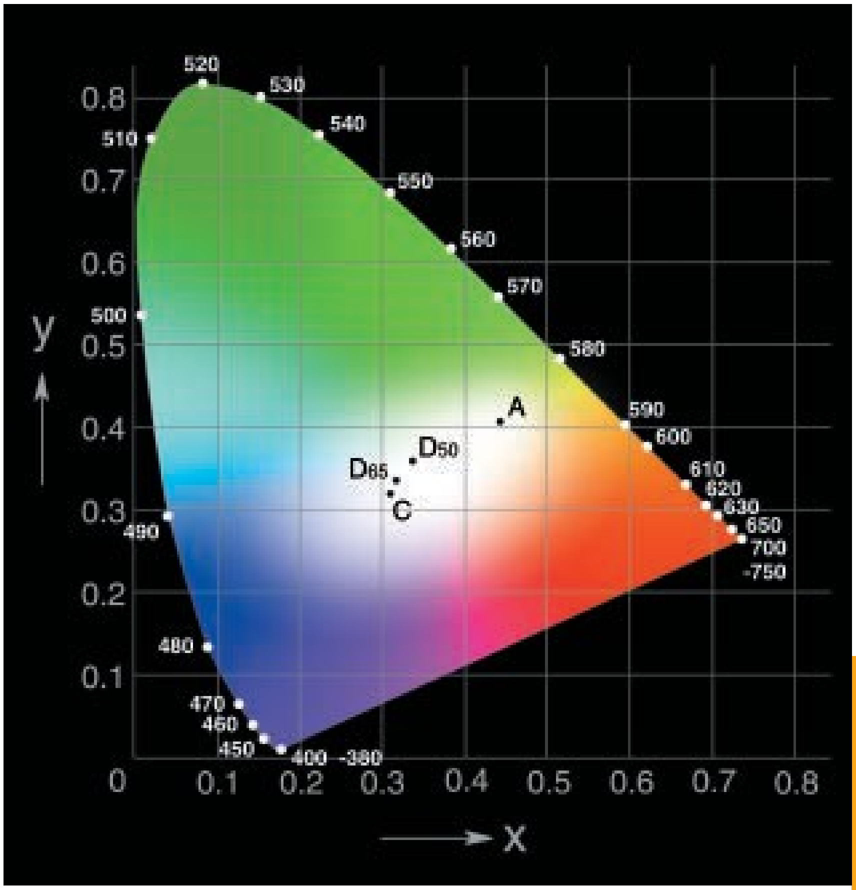


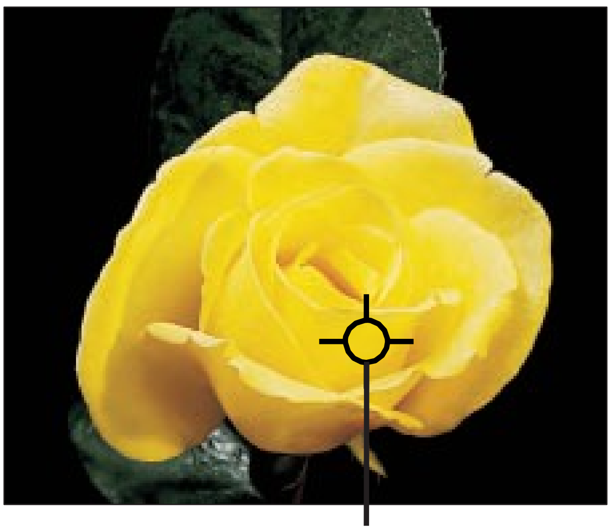
Figure 9: CIE 1931 (x, y) chromaticity diagram

Figure 10: Chromaticity diagram

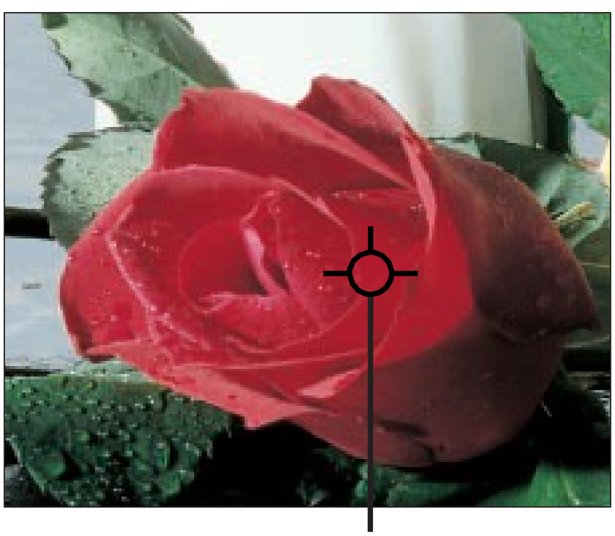
Expressing Colors Numerically

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.

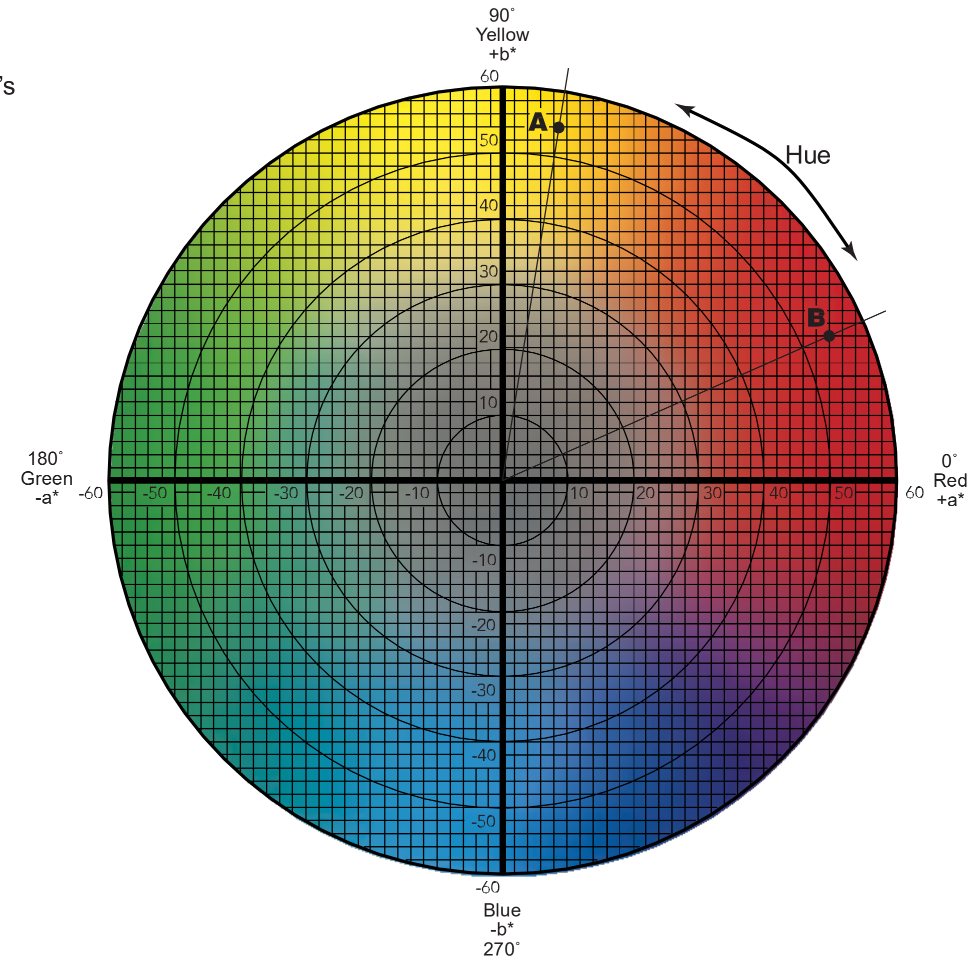


Figure 11: CIELAB color chart

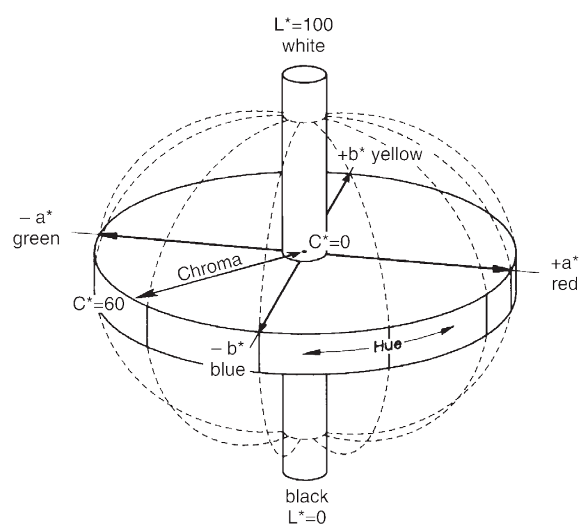


Figure 12: The L* value is represented on the center axis. The a* and b* axes appear on the horizontal plane.

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