The Munsell Scale

In 1905, artist Albert H. Munsell originated a color ordering system - or color scale - that 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.

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

Three things are necessary to see color: a light source (illuminant), an object (sample), and an observer/processor.

As humans, we 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?

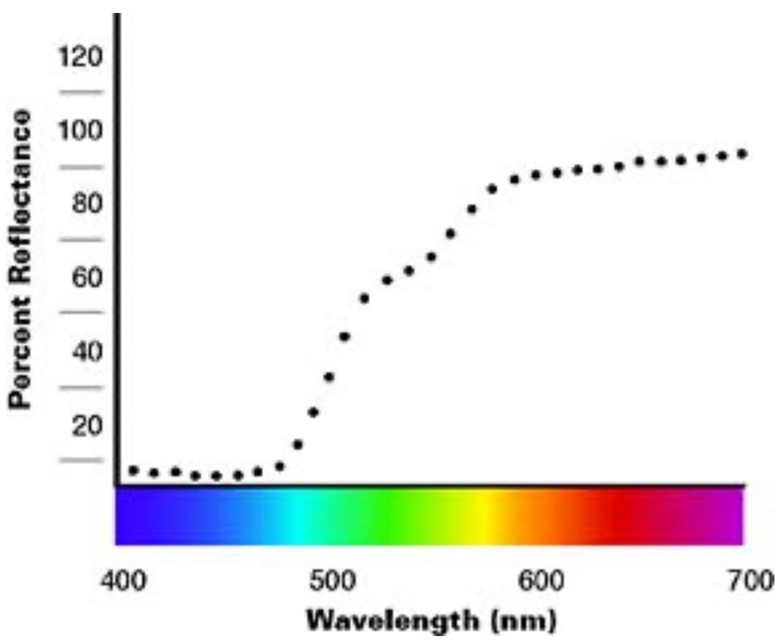

Figure 5 / Spectral Curve from a Measured Sample

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 use three coordinates to locate a color in a color space. These color spaces include CIE XYZ, CIE L*a*b* and CIE L*C*h?. To obtain these values, we must understand how they are calculated.

As stated, 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 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 (see 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 (see 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 (see 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 (see Figure 8). These values can now identify a color numerically.

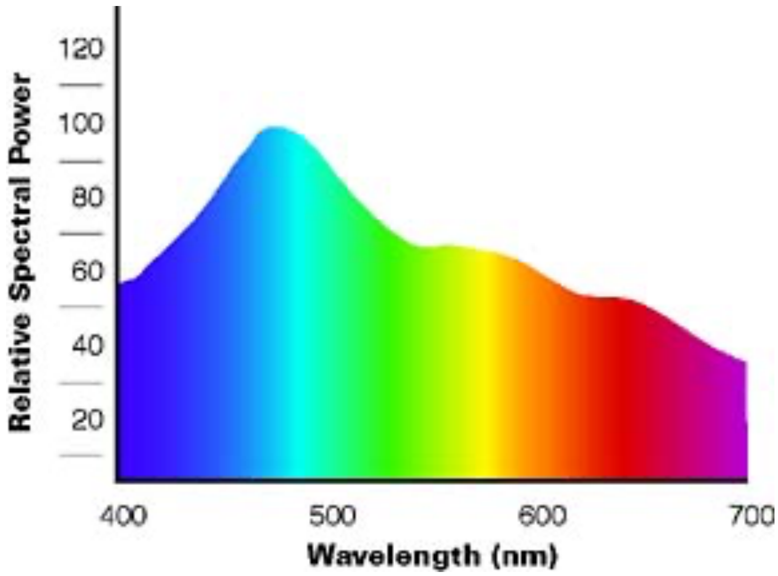

Figure 6 / Daylight (Standard Illuminant D65/10_)

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.

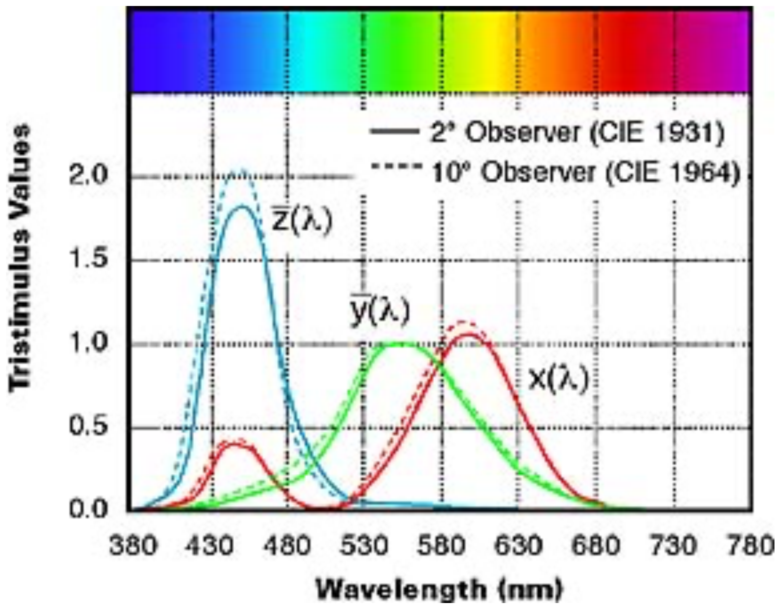

Figure 7 / CIE 2?and 10?Standard Observers

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.

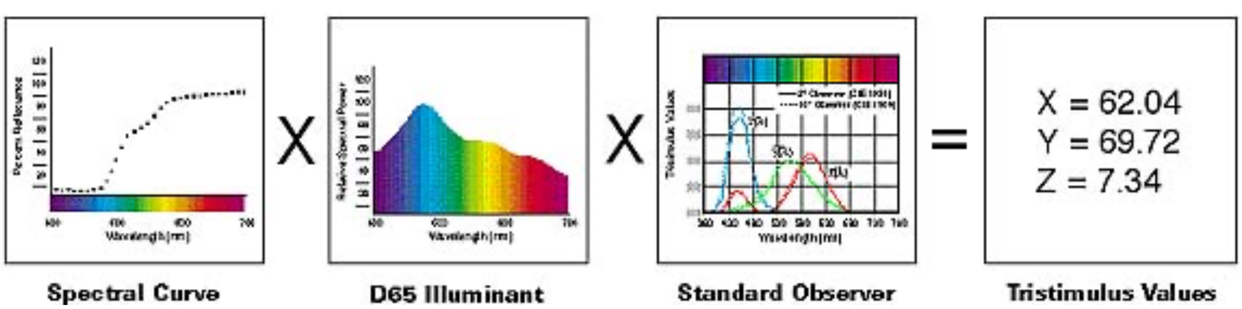

Figure 8 / Tristimulus Values

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 11-12 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, their values have been plotted on the CIELAB Color Chart in Figure 11. A and B intersect at color spaces identified respectively as points A and B. 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.

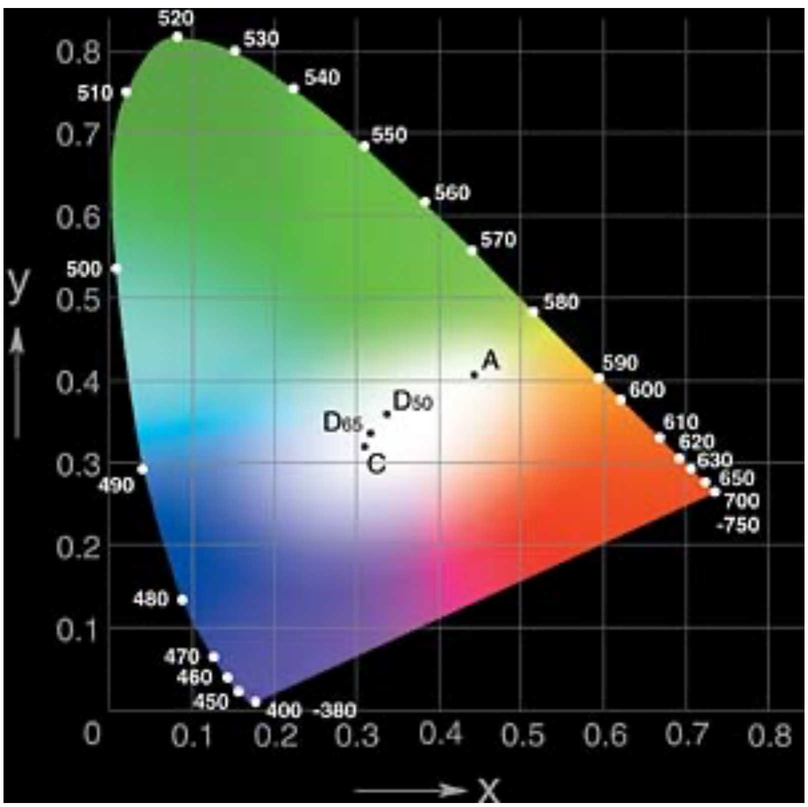

Figure 9 / CIE 1931 (x, y) Chromaticity Diagram

Color Differences, Notation and Tolerancing

Delta CIELAB

Assessment of color is more than a numeric expression. Usually it's an assessment of the color difference (delta) from a known standard. CIELAB is used to compare the colors of two objects. The expressions for these color differences are DL* Da* Db* or DL* Da* Db* (D or D symbolizes "delta," which indicates difference).

Given DL* Da* Db*, the total difference or distance on the CIELAB diagram can be stated as a single value, known as DE*.

E*ab = [(DL2) + (Da2) + (Db2)]1/2

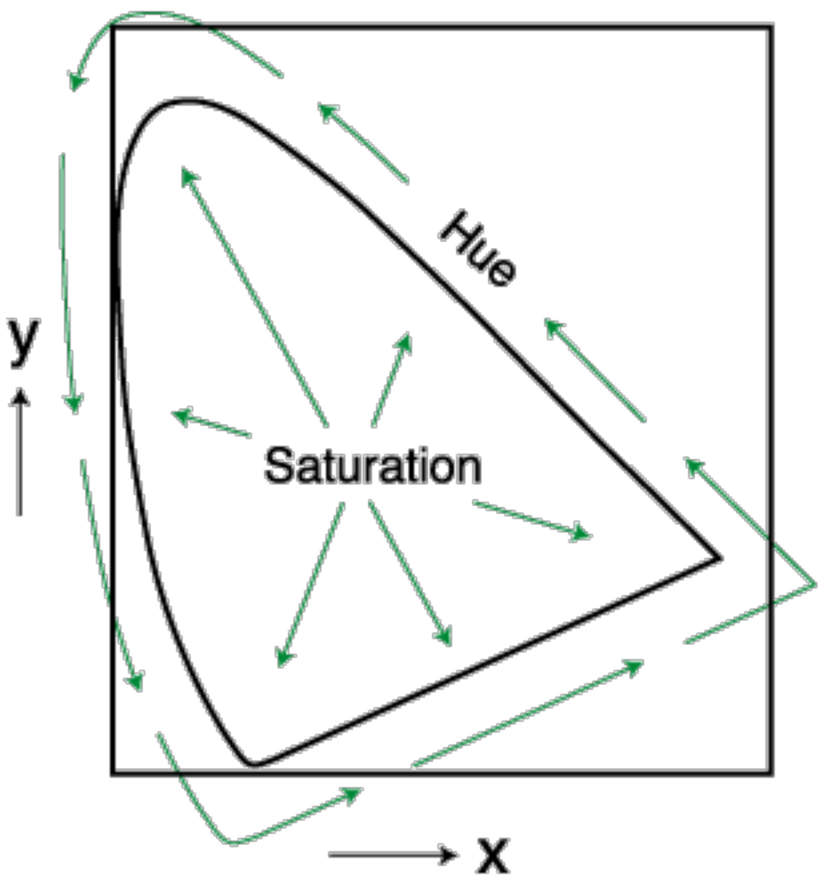

Figure 10 / Chromaticity Diagram

CIE Color Space Notation

DL* = difference in lightness/darkness value + = lighter - = darker

Da* = difference on red/green axis + = redder - = greener

Db* = difference on yellow/blue axis + = yellower - = bluer

DE* = total color difference value

Refer to Figure 11.

For more information on color, contact X Rite, phone 800/248.9748; fax 616/534.8960; visit www.x-rite.com; or e-mail info@x-rite.com

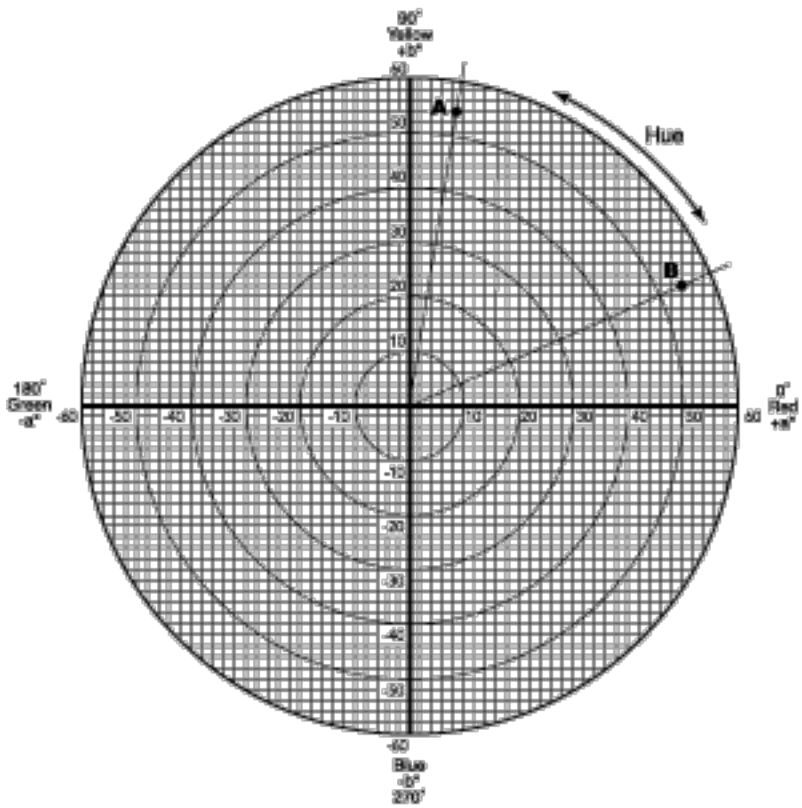

Figure 11 / CIELAB Color Chart

Applications

Spectrophotometry's applications are seemingly boundless. Color-matching measurements are made every day by those comparing a reproduced object to a reference point.

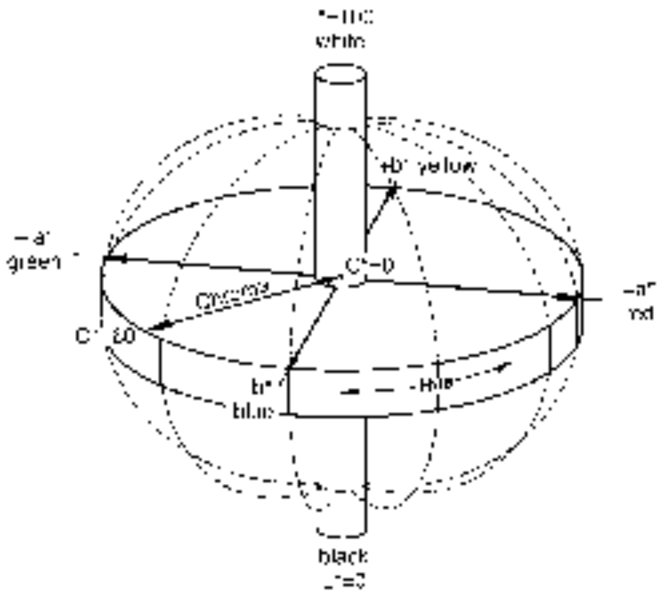

Figure 12 / The L* value is represented on the center axis. The a* and b* axes appear on the horizontal plane.

Spectrophotometry-assisted color measurement can be useful in areas including the following.

- 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.