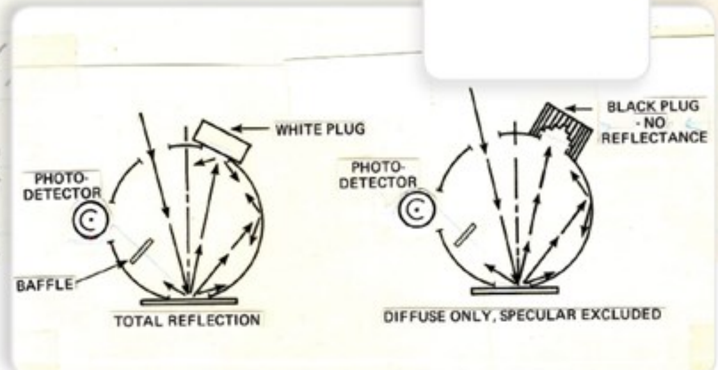
Applications Note

AN 1005



Measuring Color Using Hunter Lab vs. CIE L*a*b*

"The L,a,b scales rise above language barriers enabling companies to easily communicate color and color differences."

Abstract

Both the Hunter L, a, b scale and the CIELAB scales are intuitive. The use of these color scales with practice can easily lead to understanding and communication of color values.

This application note discusses the advantages of each scale so that the user may choose the best one to use.

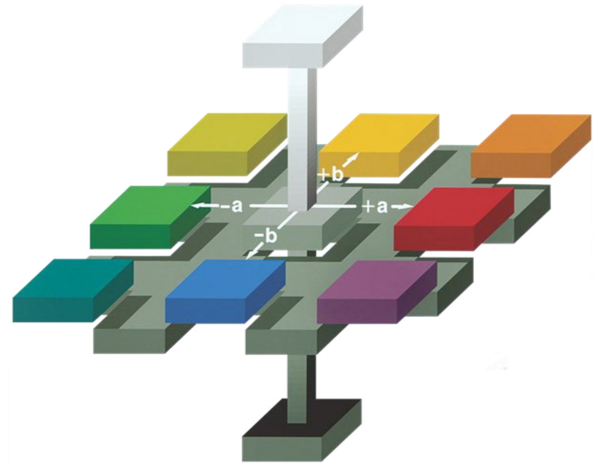
The world's true measure of color

HunterLab

Challenge: To choose the best color scale for the measurement.

Hunter L, a, b and CIE 1976 L*a*b* (CIELAB) are both color scales based on the Opponent-Color Theory. This theory assumes that the receptors in the human eye perceive color as the following pairs of opposites.

Figure 1. Opponent Color Scales of L, a, b.



- L scale: Light vs. dark where a low number (0-50) indicates dark and a high number (51-100) indicates light.
- a scale: Red vs. green where a positive number indicates red and a negative number indicates green.
- b scale: Yellow vs. blue where a positive number indicates yellow and a negative number indicates blue.

The L value for each scale therefore indicates the level of light or dark, the a value redness or greenness, and the b value yellowness or blueness. All three values are needed to completely describe an object's color. A three-dimensional representation of L, a, b color space is shown below.

Hunter Lab

The Hunter L, a, b color scale evolved during the 1950s and 1960s when many scientists involved with color measurement were working on uniform color scales. There were several permutations of the Hunter L, a, b color scale before the current formulas were released in 1966.

The Hunter L, a, b color scale is more visually uniform than the CIE XYZ color scale making it more easily understood and communicated. To the right is a diagram of the Hunter L, a, b color space. In a uniform color scale, the differences between points plotted in the color space correspond to visual differences between the colors plotted. The Hunter L, a, b color space is organized in a cube form. The L axis runs from top to bottom. The maximum for L is 100, which would be a perfect reflecting diffuser. The minimum for L would be zero, which would be black. The a and b axes have no specific numerical limits. Positive a is red. Negative a is green. Positive b is yellow. Negative b is blue.

The delta values (ΔL, Δa, and Δb) show how much a standard and sample differ from one another in L, a, and b. The ΔL, Δa, and Δb values are often used for quality control or formula adjustment. Tolerances may be set for the delta values. Delta values that are out of tolerance show that there is too much difference between the standard and the sample.

The type of correction needed may be determined by which delta value is out of tolerance. For example, if Δa is out of tolerance, the redness/ greenness needs to be adjusted. Whether the sample is redder or greener than the standard is shown by the sign of the delta value. For example, if Δa is positive, the sample is more red than the standard.

The total color difference, ΔE, may also be calculated. ΔE is a single value that considers the differences between the L, a, and b of the sample and standard. It does not show which parameter is out of tolerance if ΔE is out of tolerance. It may also be misleading in some cases where ΔL, Δa, or Δb is out of tolerance, but ΔE is still within the tolerance.

The Hunter L, a, b color scale can be used on any object whose color may be measured. It is not used as often today as it was in the past because the CIE L*a*b* scale, which was released in 1976, has gained popularity.

Conditions for Measurement

Instrument: Any HunterLab color measurement instrument
Illuminant: Any
Standard Observer Function: 2 or 10-degree
Transmittance or Reflectance: Either
Formulas:

$$L = 100\sqrt{\frac{Y}{Y_n}}$$

$$a = K_a\left(\frac{X/X_n - Y/Y_n}{\sqrt{Y/Y_n}}\right)$$

$$b = K_b\left(\frac{Y/Y_n - Z/Z_n}{\sqrt{Y/Y_n}}\right)$$

where

X, Y, and Z are the CIE tristimulus values.

X_n, Y_n, and Z_n are the tristimulus values for the illuminant.

Y_n is 100.00.

X_n and Z_n are listed in the tables below.

K_a and K_b are chromaticity coefficients for the illuminant and are listed in the tables below.

	CIE 2-degree Standard Observer				CIE 10-degree Standard Observer			
Illuminant	X_n	Z_n	K_a	K_b	X_n	Z_n	K_a	K_b
A	109.83	35.55	185.20	38.40	111.16	35.19	186.30	38.20
C	98.04	118.11	175.00	70.00	97.30	116.14	174.30	69.40
D_{65}	95.02	108.82	172.30	67.20	94.83	107.38	172.10	66.70
F2	98.09	67.53	175.00	52.90	102.13	69.37	178.60	53.60
TL 4	101.40	65.90	178.00	52.30	103.82	66.90	180.10	52.70
UL 3000	107.99	33.91	183.70	37.50	111.12	35.21	186.30	38.20
D_{50}	96.38	82.45	173.51	58.48	96.72	81.45	173.82	58.13
D_{60}	95.23	100.86	172.47	64.72	95.21	99.60	172.45	64.28
D_{75}	94.96	122.53	172.22	71.30	94.45	120.70	171.76	70.76

$\Delta L = L_{sample} - L_{standard}$

+ ΔL means sample is lighter than standard
- ΔL means sample is darker than standard

$\Delta a = a_{sample} - a_{standard}$

+ Δa means sample is redder than standard
- Δa means sample is greener than standard

$\Delta b = b_{sample} - b_{standard}$

+ Δb means sample is yellower than standard
- Δb means sample is bluer than standard.

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}\,.$$

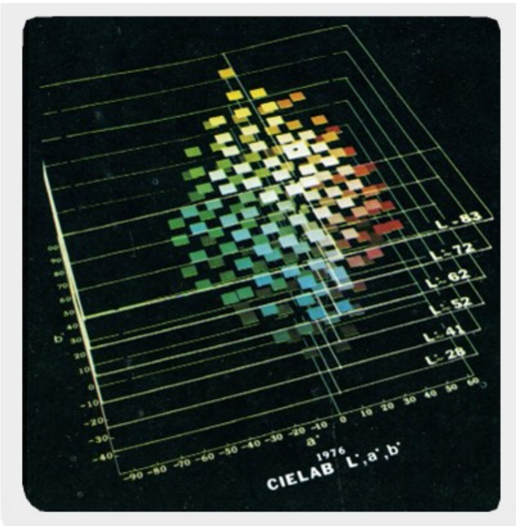
CIE L*a*b*

The CIELAB color scale is another uniform color scale recommended by the International Commission on Illumination (CIE) in 1976 to improve on the 1966 version of the Hunter L, a, b. It is in wide spread use today in many industries. It expresses color as three values: *L** for perceptual lightness and *a** and *b** for the four unique colors of human vision: red, green, blue and yellow.

Background

In 1976, the CIE recommended the CIE L*a*b*, or CIELAB, color scale for use. CIE Publication 15.2 (1986), Section 4.2, contains details on this color scale. It was intended to provide a standard, approximately uniform color scale which could be used by everyone so that color values could be easily compared.

The CIELAB color scale is an approximately uniform color scale. In a uniform color scale, the differences between points plotted in the color space correspond to visual differences between the colors plotted. The CIELAB color space is organized in a cube form. The L* axis runs from top to bottom. The maximum for L* is 100, which represents a perfect reflecting diffuser. The minimum for L* is zero, which represents black. The a* and b* axes have no specific numerical limits. Positive a* is red. Negative a* is green. Positive b* is yellow. Negative b* is blue. Below is a diagram representing the CIELAB color space.



There are delta values associated with this color scale. dL*, da*, and db* indicate how much a standard and sample differ from one another in L*, a*, and b*. These delta values are often used for quality control or formula adjustment. Tolerances may be set for the delta values. Delta values that are out of the tolerances indicate that there is too much difference between the standard and the sample. The type of correction needed may be determined by which delta value is out of tolerance. For example, if da* is out of tolerance, the redness/greenness needs to be adjusted. Whether the sample is redder or greener than the standard is indicated by the sign of the delta value. For example, if da* is positive, the sample is redder than the standard.

The total color difference, dE*, may also be calculated. The dE* is a single value which takes into account the differences between the L*, a*, and b* of the sample and standard. It does not indicate which parameter(s) (L*, a*, and/or b*) are out of tolerances if dE* is out of tolerance. It may also be misleading in some cases where dL*, da*, or db* is out of tolerance, but dE* is still within tolerance.

In addition, there are two other delta values that are related to this scale, DC* and DH*. The DC* is the difference in chroma between the sample and standard as described in a polar coordinate system. The DH* is the difference in hue angle between the sample and standard as described in a polar coordinate system.

The CIELAB color scale may be used on any object whose color may be measured. It is used extensively in many industries. As was intended, it provides a standard scale for comparison of color values.

Conditions for Measurement

Instrumental: Any HunterLab color measurement instrument
Illuminant: Any
Standard Observer Function: 2 or 10 degree
Transmittance and/or Reflectance: Either
Formulas:

If X/X_n, Y/Y_n, and Z/Z_n are all greater than 0.008856, then

$$L^* = 116\sqrt[3]{Y/Y_n} - 16$$

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

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

If any of X/X_n, Y/Y_n, or Z/Z_n is equal to or less than 0.008856, then

$$L^* = 903.3\,(Y/Y_n)$$

$$a^* = 500\left[f\,(X/X_n) - f\,(Y/Y_n)\right]$$

$$b^* = 200\left[f\,(Y/Y_n) - f\,(Z/Z_n)\right]$$

where

X, Y, and Z are the CIE Tristimulus Values

X_n, Y_n, and Z_n are the tristimulus values for the illuminant

Y_n is 100.00

X_n and Z_n are listed in the tables below.

	CIE 2-degree Standard Observer		CIE 10-degree Standard Observer	
Illuminant	X_n	Z_n	X_n	Z_n
A	109.83	35.55	111.16	35.19
C	98.04	118.11	97.30	116.14
D_{65}	95.02	108.82	94.83	107.38
F2	98.09	67.53	102.13	69.37
TL 4	101.40	65.90	103.82	66.90
UL 3000	107.99	33.91	111.12	35.21
D_{50}	96.38	82.45	96.72	81.45
D_{60}	95.23	100.86	95.21	99.60
D_{75}	94.96	122.53	94.45	120.70

$$f(X/X_n) = \sqrt[3]{X/X_n} \quad \text{when } X/X_n > 0.008856$$

$$f(X/X_n) = 7.87\left(\frac{X}{X_n}\right) + \frac{16}{116} \quad \text{when } X/X_n < 0.008856$$

$$f(Y/Y_n) = \sqrt[3]{Y/Y_n} \quad \text{when } Y/Y_n > 0.008856$$

$$f(Y/Y_n) = 7.87\left(\frac{Y}{Y_n}\right) + \frac{16}{116} \quad \text{when } Y/Y_n < 0.008856$$

$$f(Z/Z_n) = \sqrt[3]{Z/Z_n} \quad \text{when } Z/Z_n > 0.008856$$

$$f(Z/Z_n) = 7.87\left(\frac{Z}{Z_n}\right) + \frac{16}{116} \quad \text{when } Z/Z_n < 0.008856$$

$\Delta L^* = L^*_{sample} - L^*_{standard}$

+ ΔL^* means sample is lighter than standard

- ΔL^* means sample is darker than standard

$\Delta a^* = a^*_{sample} - a^*_{standard}$ + Δa^* means sample is redder than standard
- Δa^* means sample is greener than standard

$\Delta b^* = b^*_{sample} - b^*_{standard}$ + Δb^* means sample is yellower than standard
- Δb^* means sample is bluer than standard

$$\Delta E^* = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$

$$\Delta C^* = C^*_{sample} - C^*_{standard}$$

where

$$C^* = \sqrt{a^{*2} + b^{*2}}$$ (this is called metric chroma)

$$\Delta H^* = \sqrt{\Delta E^{*2} - \Delta L^{*2} - \Delta C^{*2}}$$

Which Scale Should I Use?

The formulas are calculated differently with Hunter L, a, and b using square roots and using CIELAB is calculated using cube roots of CIE XYZ.

The perfect color scale would be uniform throughout color space, meaning that a one unit difference between two colors would appear to be visually different by the same amount whether red, purple, orange, or blue. In truth, neither Hunter L, a, b nor CIELAB is perfectly uniform. The Hunter L, a, b scale contracts in the yellow region of color space and expands in the blue region. The CIELAB scale expands in the yellow region and this is more obvious when a sample's CIE Z value is less than one. The CIELAB scale gives better approximation to visual evaluation of color difference for very dark colors.

Conclusion

Both color scales are good selections when looking for a new method for a new type of sample. If a color measuring instrument is being requested to meet a customer's requirement, then the customer may have a preference of scales. Industries often have specific requirements as spelled out in ASTM methods and more.

Criteria For Comparison Hunter L,a,b To CIE L*a*b*		
Criteria	**Hunter L, a, b**	**CIE L*a*b***
Mathematical Function	Square root function of CIE XYZ	Cube root function of CIE XYZ
Specifications or Methods	Color specifications or methods indicate Hunter L, a, b such as in the food industry	Color specifications or methods indicate CIE LAB
Frequency of Use	Used less	Widespread use
Comparison to Previous Data	Historical color data was recorded in Hunter L, a, b	Historical color data was recorded in CIE LAB
Color Space Sensitivity	Measuring blues more than yellows	Measuring yellows more than blues and dark colors

References

Hunter, Richard S., and Harold, Richard W; The Measurement of Appearance, 2nd ed., John Wiley and Sons, Inc. New York, NY USA, 1987.

CIE International Commission on Illumination, Recommendations on Uniform Color Spaces, Color-Difference Equations, Psychometric Color Terms, Supplement No. 2 to CIE Publication No. 15, Colorimetry, 1971 and 1978.

About HunterLab

HunterLab is the technology leader in color measurement solutions, providing instruments, software, knowledge and service to a wide variety of industries.
With over 5 decades of experience in more than 65 countries, HunterLab applies our leading edge technology to your products helping you measure and communicate color simply and effectively.

 12/2023

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