Things Required

To See Color

Light Source

Object

Observer

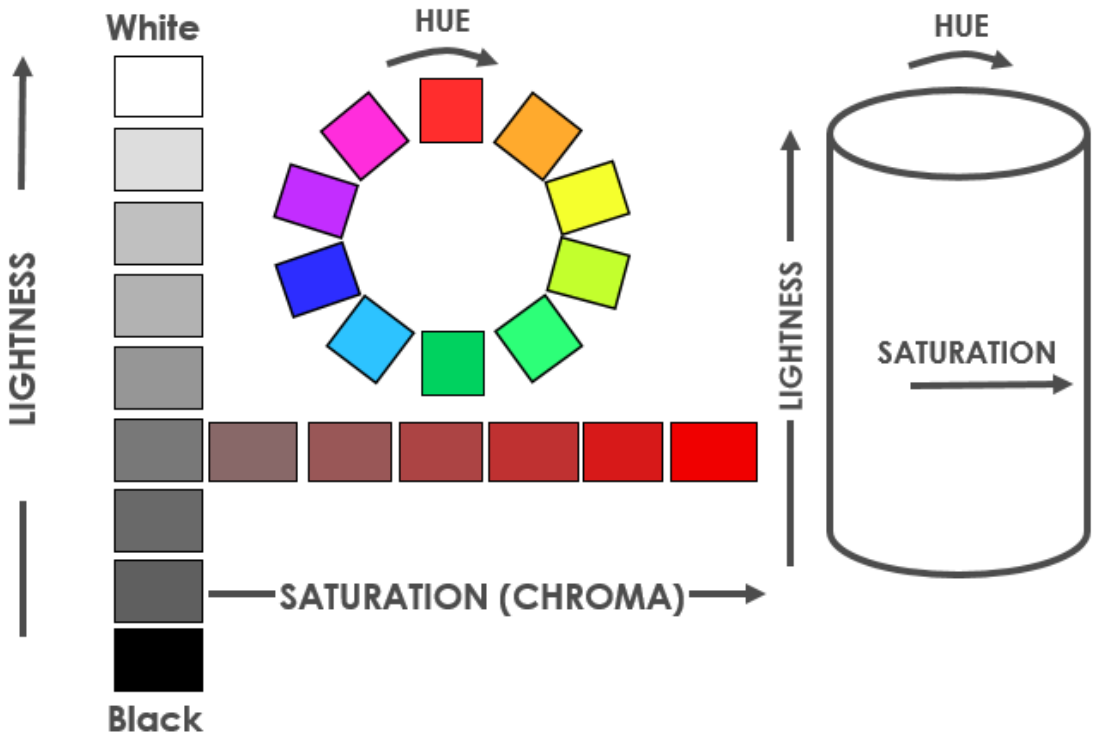
To Measure Color

Light Source

Sample

Spectrophotometer

Visual Organization of Color



Measured Color Values

- Visual evaluation of color is **subjective** and **approximate**.
- Measuring color using an instrument provides **objective** and **precise** results that correlate to human perception.

“School Bus Yellow” Measured Values

X = 41.9
Y = 37.7
Z = 8.6

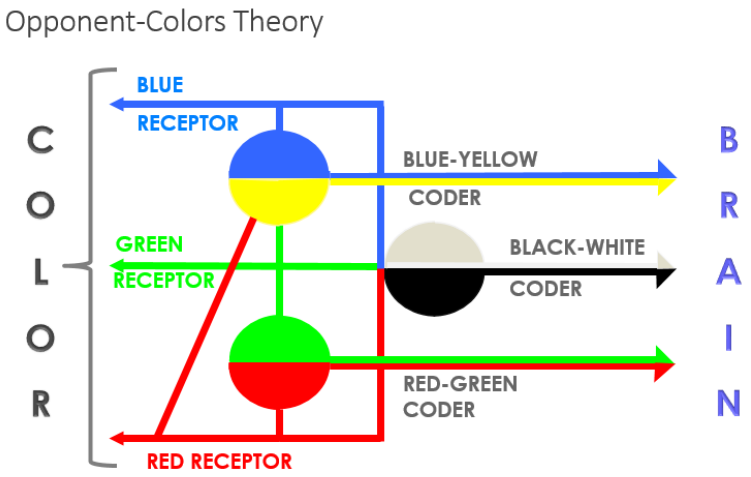
Color Scales

In terms of object color, X, Y, Z values are not easily understood. Other color scales have been developed to:

- Better relate how we perceive color.
- Simplify understanding.
- Improve communication of color.
- Better represent uniform color differences.

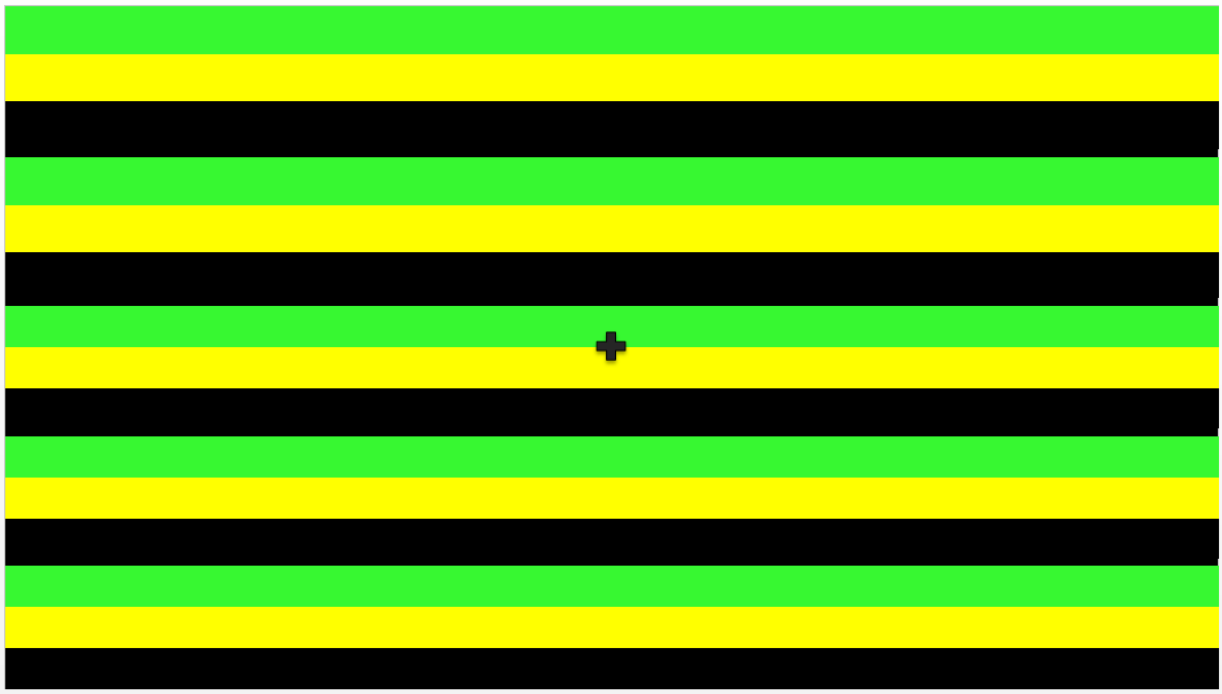
Opponent-Colors Theory

- States red, green and blue cone responses are remixed into opponent coders as they move up the optic nerve to the brain.



Opponent-Colors Theory

- When the next slide appears, focus on the black cross in the center of the stripes until the slide automatically changes to the white screen (after about 20 seconds).



Opponent-Colors Theory

Did you see the stripes as red, white and blue?

This happens because the green, black and yellow stripes saturate the cone responses.

When you look at the blank screen your vision tries to return to balance and you see a red, white and blue after-image.

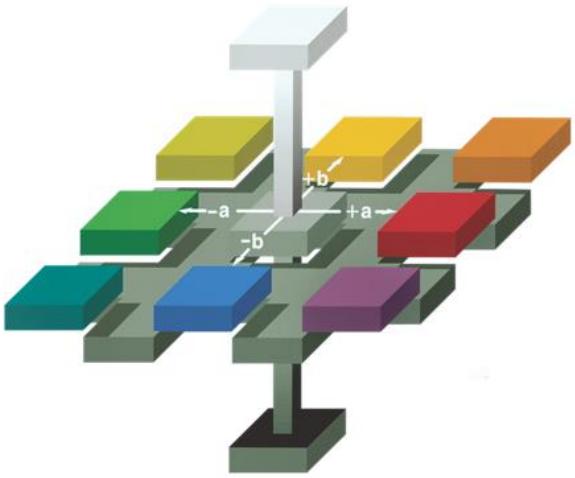
This demonstration supports the Opponent-Colors Theory

Hunter L,a,b Color Space

Hunter L,a,b color space is a 3-dimensional **rectangular** color space based on Opponent-Colors Theory.

- **L** (lightness) axis - 0 is black, 100 is white, and 50 is middle gray
- **a** (red-green) axis - positive values are red, negative values are green, and 0 is neutral
- **b** (blue-yellow) axis - positive values are yellow, negative values are blue, and 0 is neutral

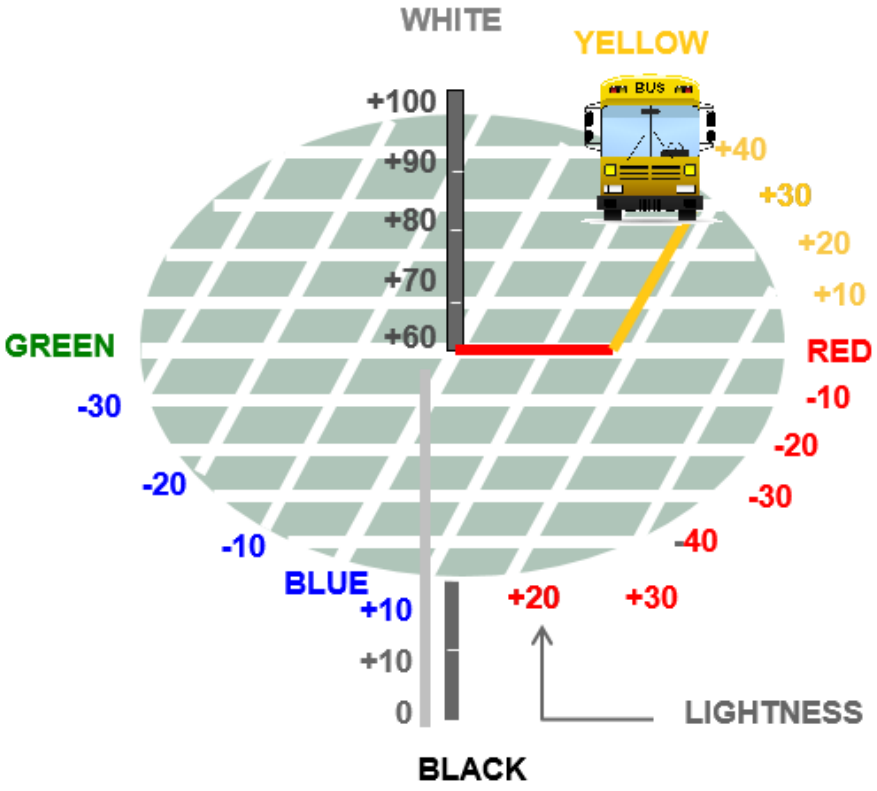
Hunter L,a,b Color Space



Hunter L, a, b Color Space

- All colors can be represented in L, a, b rectangular color space.

- The following slide shows where “school bus yellow” falls in Hunter L, a, b color space.



L= 61.4

a= + 18.1

b = +32.2

Hunter L, a, b Values for "School Bus Yellow"

L = 61.4

a = + 18.1

b = + 32.2

L, a, b Color Scales

- There are two popular L,a,b color scales in use today: **Hunter L,a,b** and **CIE L*,a*,b*.**
- While similar in organization, a color will have different numerical values in these two color spaces.

Hunter L, a, b versus CIE L*,a*, b*

Hunter L, a, b (1958)

L = 61.42
a = + 18.11
b = + 32.23

CIE L*,a*,b* (1976)

L * = 67.81
a* = + 19.56
b* = + 58.16

L, a, b Color Scales

- Hunter L, a, b and CIE L*,a*,b* scales are both mathematically derived from CIE X, Y, Z values.
- Neither scale is visually uniform. Hunter L, a, b is over expanded in the blue region of color space and CIE L*,a*,b* is over expanded in the yellow region.
- **The current CIE recommendation is to use L*,a*,b*.**

Calculation of Color Formulas

Hunter L, a, b	CIE L*, a*, b*
$L = 100\,(Y/Y_n)^{1/2}$	$L^* = 116\,(Y/Y_n)^{1/3} - 16$
$a = \dfrac{Ka\,(X/X_n - Y/Y_n)}{(Y/Y_n)^{1/2}}$	$a^* = 500\,[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}]$
$b = \dfrac{Kb\,(Y/Y_n - Z/Z_n)}{(Y/Y_n)^{1/2}}$	$b^* = 200\,[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}]$

What is an Acceptable Color Difference?

Maximum Acceptable

Minimum Perceptible

What is an Acceptable Color Difference?

What is an acceptable color difference varies with the application.

For example:

- What is acceptable for color matching of automotive paint is close to being a **minimum perceptible** limit.
- What is acceptable for snack foods is greater and the **maximum acceptable limit** defines the tolerance for the product.

Rectangular ΔL*, Δa*, Δb* Color Differences

Color Differences are always calculated as **SAMPLE - STANDARD** values.

- If **delta L*** is **positive**; the sample is **lighter** than the standard.
  If **negative**; it would be **darker** than the standard.

- If **delta a*** is **positive**; the sample is **more red** (or **less green**)than the standard.
  If **negative**; it would be **more green** (or **less red**).

- If **delta b*** is **positive**; the sample is **more yellow** (or **less blue**) than the standard.
  If **negative**; it would be **more blue** (or **less yellow**).

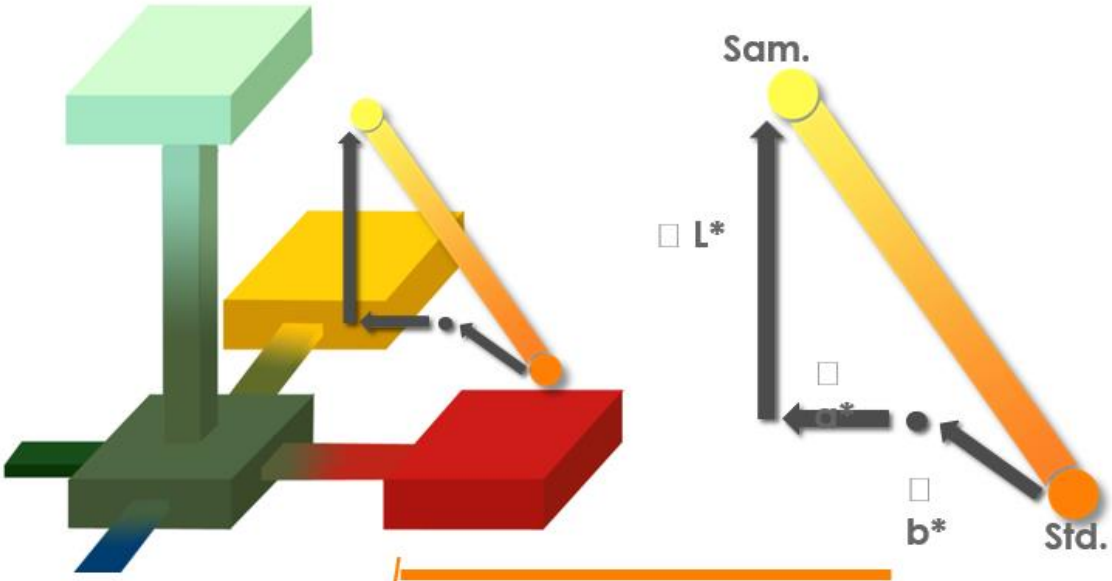
Rectangular ΔL*, Δa*, Δb* Color Differences

L*	=	71.9	L*	=	69.7	Δ L* =	+2.2
a*	=	+10.2	a*	=	+12.7	Δ a* =	-2.5
b*	=	+58.1	b*	=	+60.5	Δ b* =	-2.4

Delta E* (Total Color Difference)

- **Δ E*** is based on **L*,a*,b*** color differences and was intended to be a single number metric for **PASS/FAIL** decisions.

Delta E* (Total Color Difference)



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