Coloring of Plastics
Color Education

Presented by: The Color and Appearance Division

Education Committee

Originally Created July 2007

Last Modification May 2020

Color Education
Purpose and Scope

This Color Education presentation provides fundamental concepts of color and appearance for use by anyone educating students, professionals, and organizations.

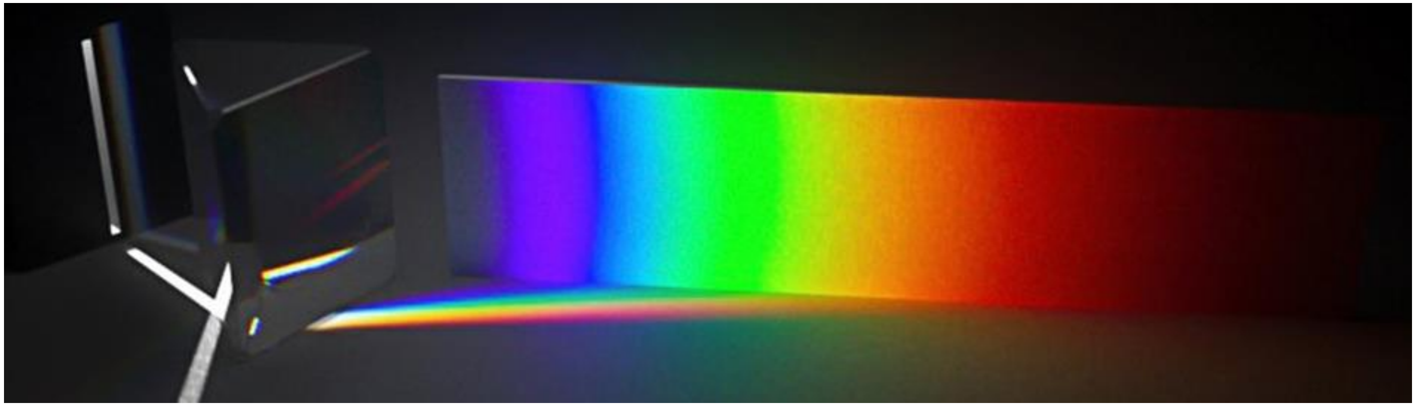
The scope of the presentation covers colorimetry with definitions and images selected by the Education Committee members of the Society of Plastics Engineers (SPE) – Color and Appearance Division (CAD) Board of Directors that best represents the theory and practice used in today’s coloring of plastics industry.

Color Education

Sections I – VI

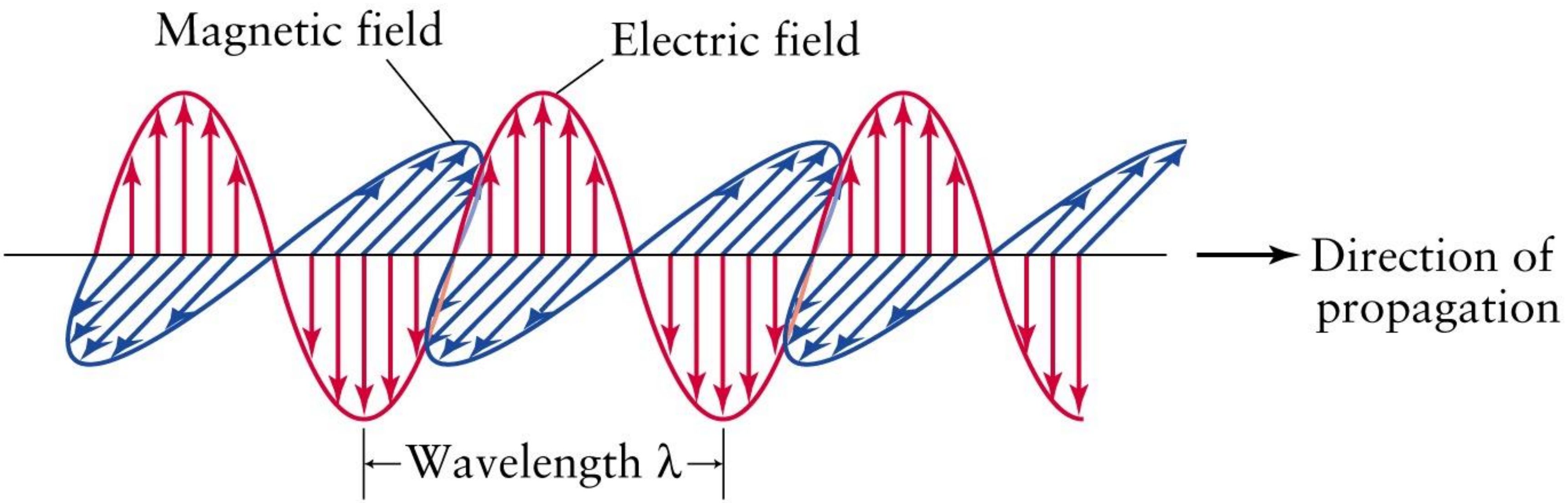
Section I – Color Science

Opticks " …if the Sun's Light consisted of but one sort of Rays, there would be but one Colour in the whole World…



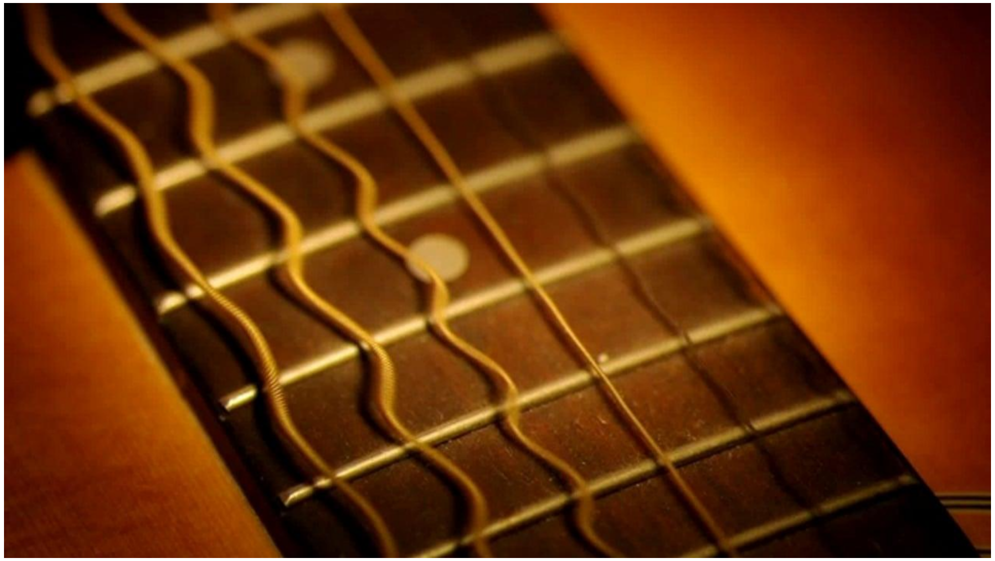
Light

- Electromagnetic energy (electromagnetic radiation)
- Electromagnetic energy interacts with matter

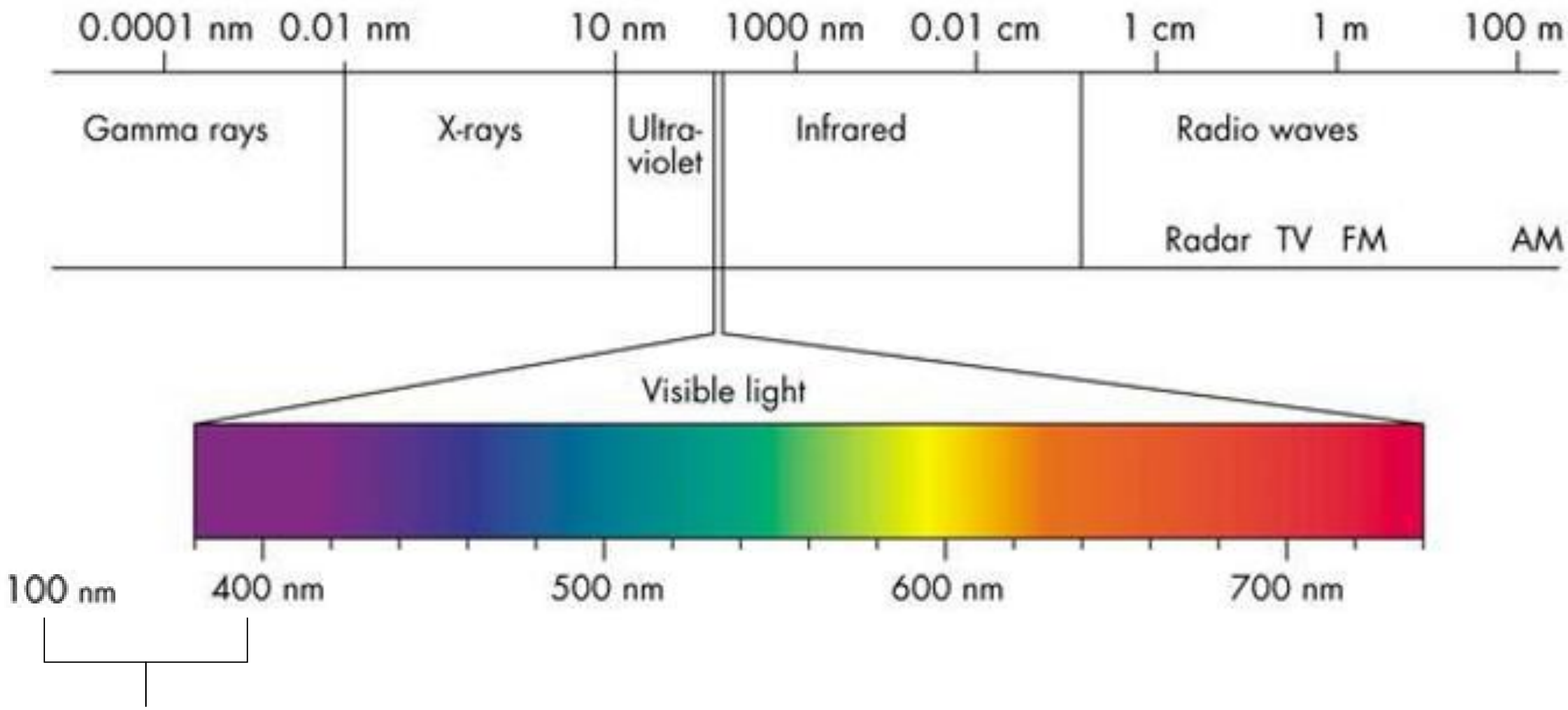


physast.uga.edu

Wavelength



Visible Spectrum



Ultraviolet C UVC 100–280nm Short-wave, germicidal, completely absorbed by ozone layer/atmosphere

Ultraviolet B UVB 280–315nm Medium-wave, mostly absorbed by ozone layer

Ultraviolet A UVA 315–400nm Long-wave, black light, not absorbed by the ozone layer

Light interacts with an object

electromagnetic radiation ϑ (zeta) = 1.0 or 100%

Absorbed
\+ Reflected
\+ Transmitted
ϑ (zeta)

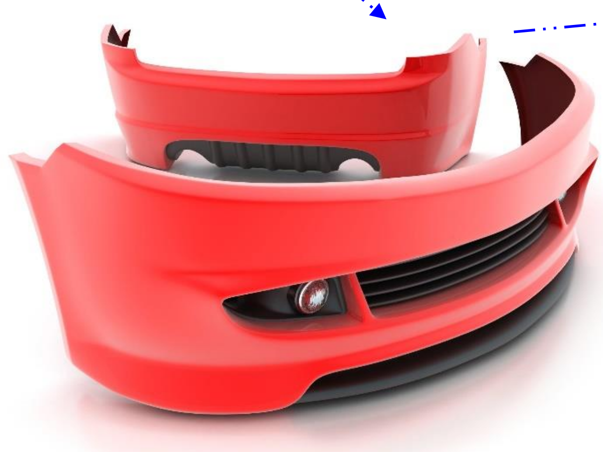
Transparency
Translucency
Opaqueness
Surface Texture

Color
and
Appearance

Color and Color Appearance

The three elements of color vision

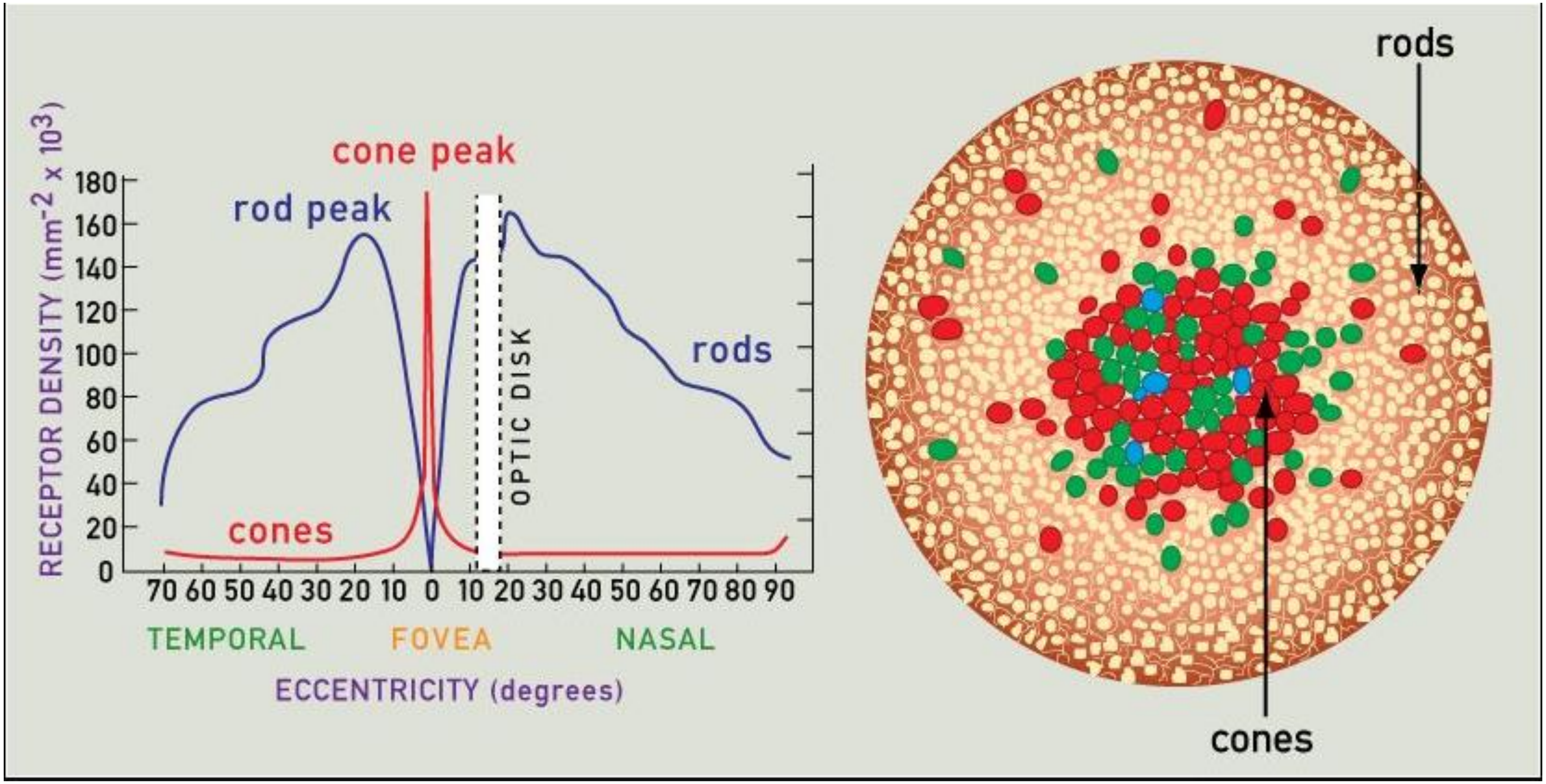
Light Source



Object

Observer

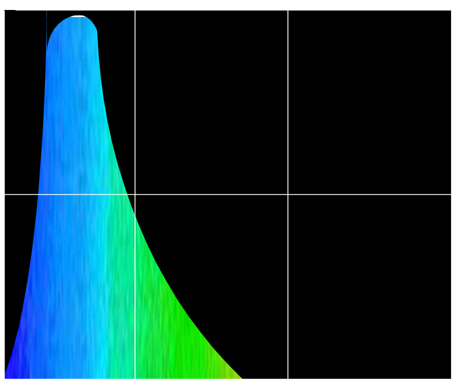
Human Observer



Douma, Michael, curator. "Light Bulb," Cause of Color, 2008, http://www.webexhibits.org/causesofcolor/3.html, (accessed January 1, 2008).

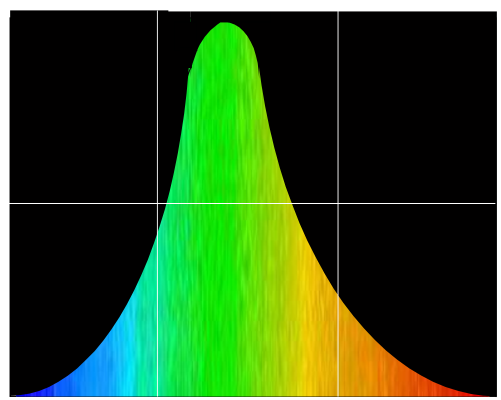
Visual Response
Tristimulus Response Functions

Short



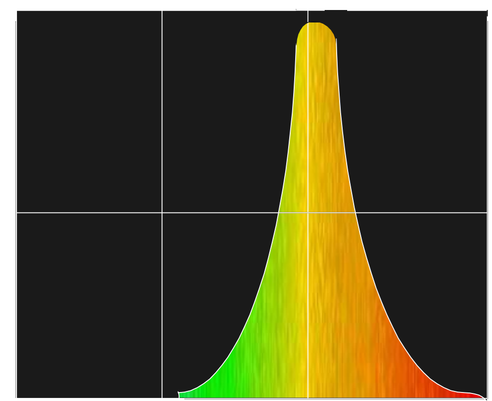
Blue

Medium



Green

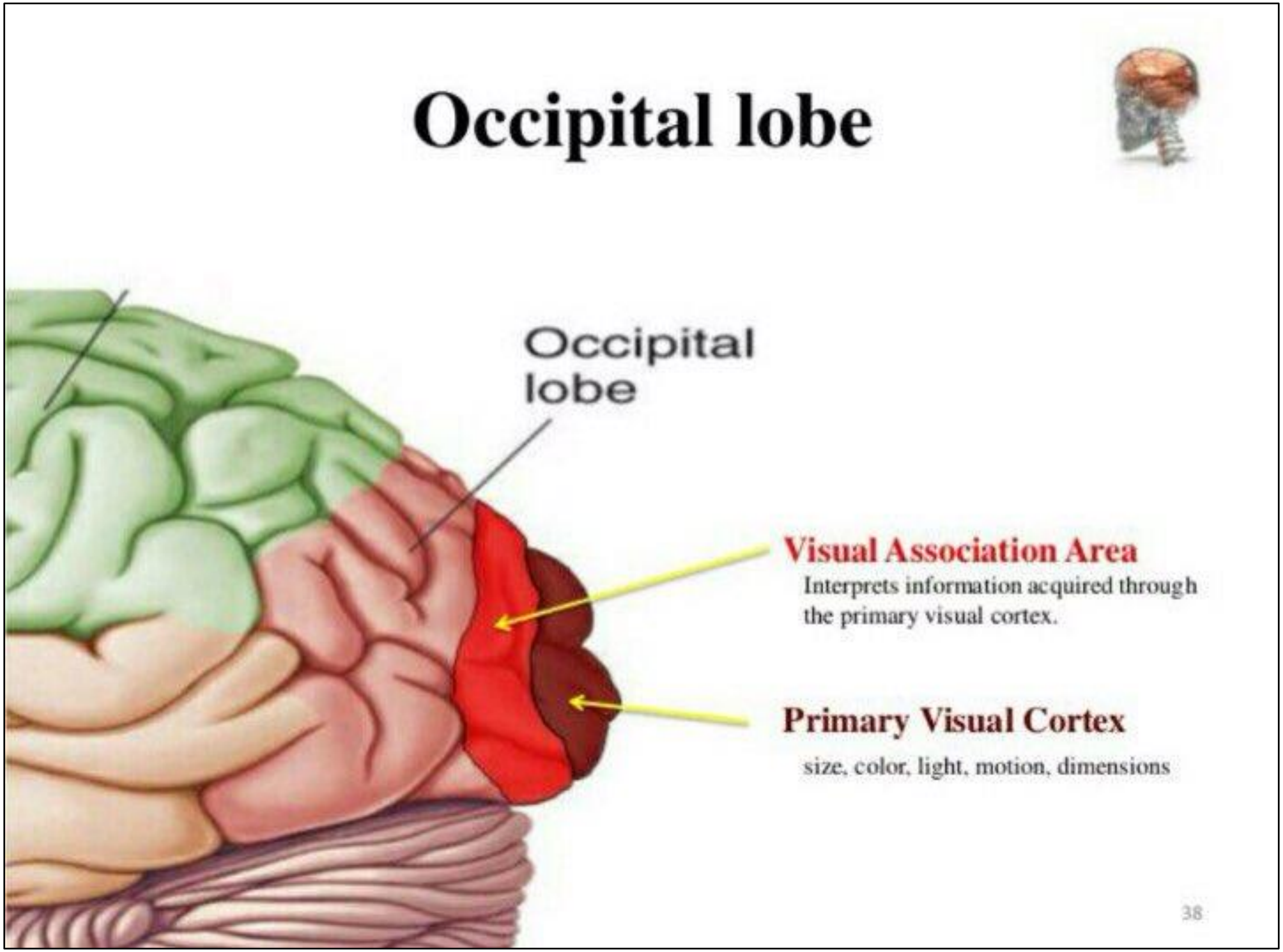
Long



Red

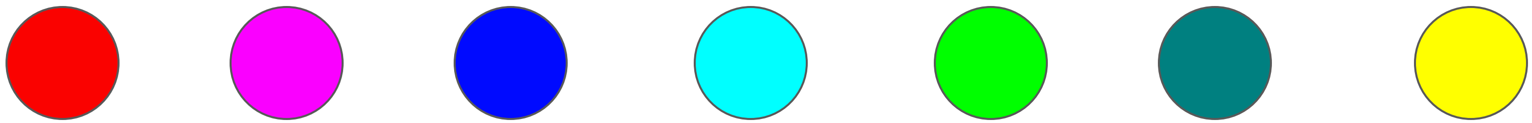
(r,g,b)

Physiological Interpretation

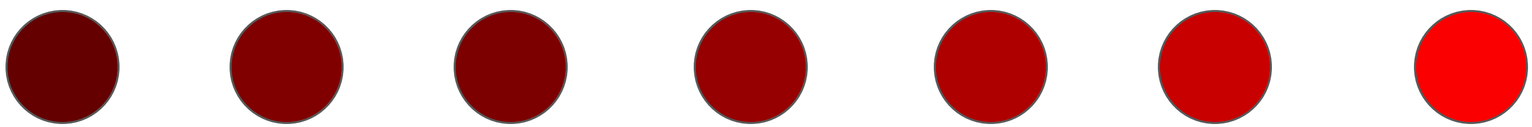


Color Attribute Identification

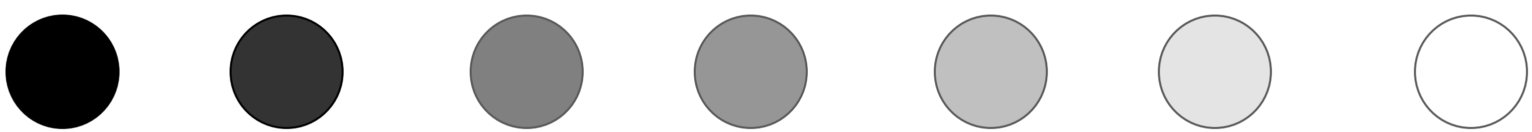
Hue



Chromaticity

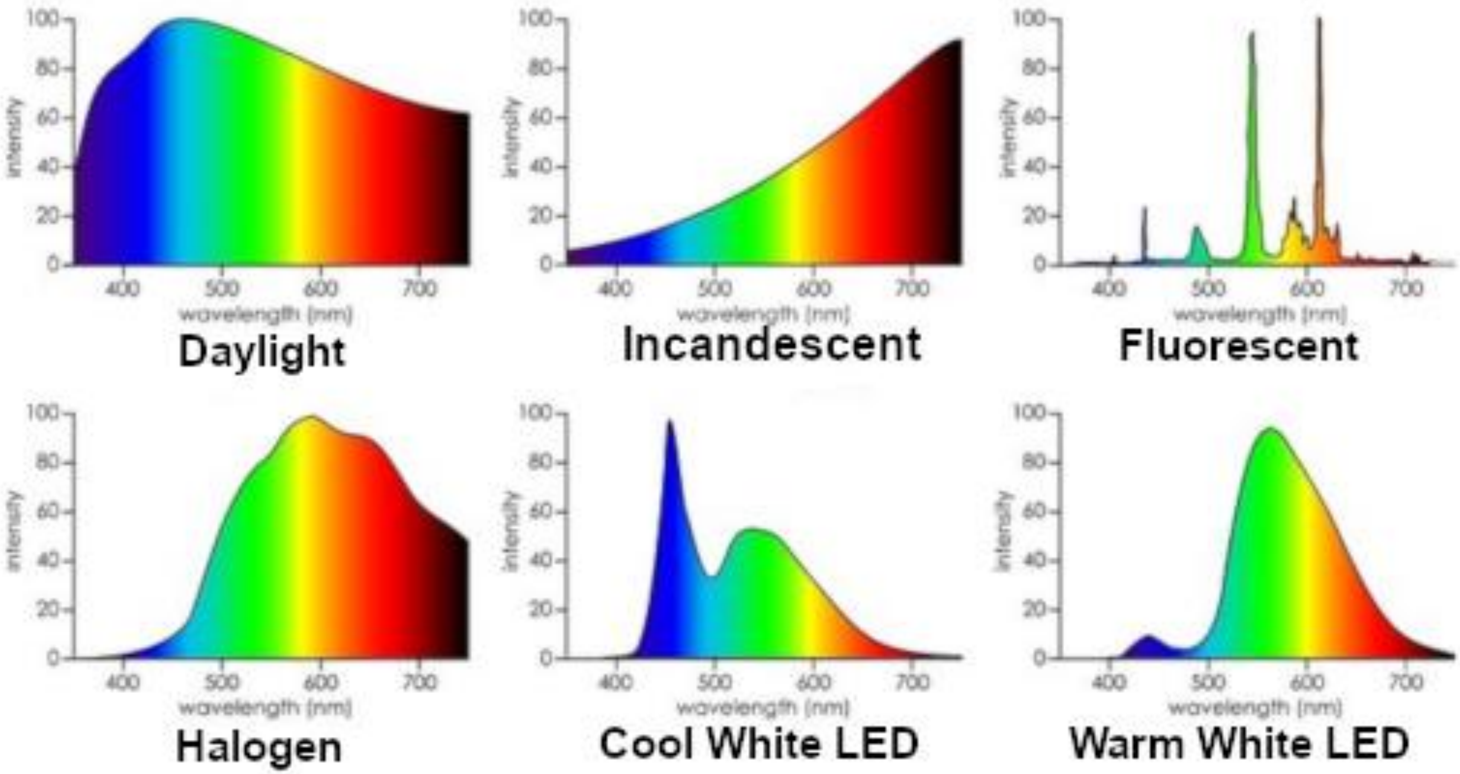


Value or Lightness/Darkness



Light Source

Spectral Power Distribution



https://www.paintingframesplus.com/painting-frames-plus-website-colors.php

Light Sources

Name	CCT (K)	Note
A	2856	Incandescent / Tungsten
B	4874	{obsolete} Direct sunlight at noon
C	6774	{obsolete} Average / North sky Daylight
D50	5003	Horizon Light
D55	5503	Mid-morning / Mid-afternoon Daylight
D65	6504	Noon Daylight
D75	7504	North sky Daylight
E	5454	Equal energy
F1	6430	Daylight Fluorescent
F2	4230	Cool White Fluorescent
F3	3450	White Fluorescent
F4	2940	Warm White Fluorescent
F5	6350	Daylight Fluorescent
F6	4150	Lite White Fluorescent
F7	6500	D65 simulator, Daylight simulator
F8	5000	D50 simulator, Sylvania F40 Design 50
F9	4150	Cool White Deluxe Fluorescent
F10	5000	Philips TL85, Ultralume 50
F11	4000	Philips TL84, Ultralume 40
F12	3000	Philips TL83, Ultralume 30

Kelvin

Narrow Band

Standardizing Color Qualities

Billmeyer and Saltzman second addition

COLOR & APPEARANCE

The Six Levels of the Universal Color Language (Kelly 1976)

	Color name designations			Numeral and/or letter color designations		
Level of fineness of color designation	Level 1 (least precise)	Level 2	Level 3	Level 4	Level 5	Level 6 (most precise)
Number of divisions of color solid	13	29	267[a]	943–7056[a]	≃100,000	≃5,000,000
Type of color designation	Generic hue names and neutrals (see circled designations in diagram below)	All hue names and neutrals (see diagram below)	ISCC-NBS All hue names and neutrals with modifiers	Color-order systems (collections of color standards sampling the color solid systematically)	Visually interpolated Munsell Notation (From *Munsell Book of Color*)	CIE (x, y, Y) or instrumentally interpolated Munsell Notation
Examples of color designation	Brown	Yellowish brown	Light yellowish brown (centroid #76)	Munsell 10YR 6/4[b]	9$\frac{1}{2}$YR 6.4/4$\frac{1}{4}$	$x = 0.395$ $y = 0.382$ $Y = 35.6$ or 9.6YR 6.4_5/4.3[b]
General applicability	⟶ Increased fineness of color designation ⟶ ⟵ Statistical expression of color trends (roll-up method) ⟵					

[a] Figures indicate the number of color samples in each collection.
[b] The smallest unit used in the Hue, Value, and Chroma parts of the Munsell Notation in Levels 4 (1 Hue step, 1 Value step, and 2 Chroma steps), 5 ($\frac{1}{2}$ Hue step, 0.1 Value step, and $\frac{1}{4}$ Chroma step), and 6 (0.1 Hue step, 0.05 Value step, and 0.1 Chroma step) indicates the accuracy to which the parts of the Munsell Notation are specified in that level.

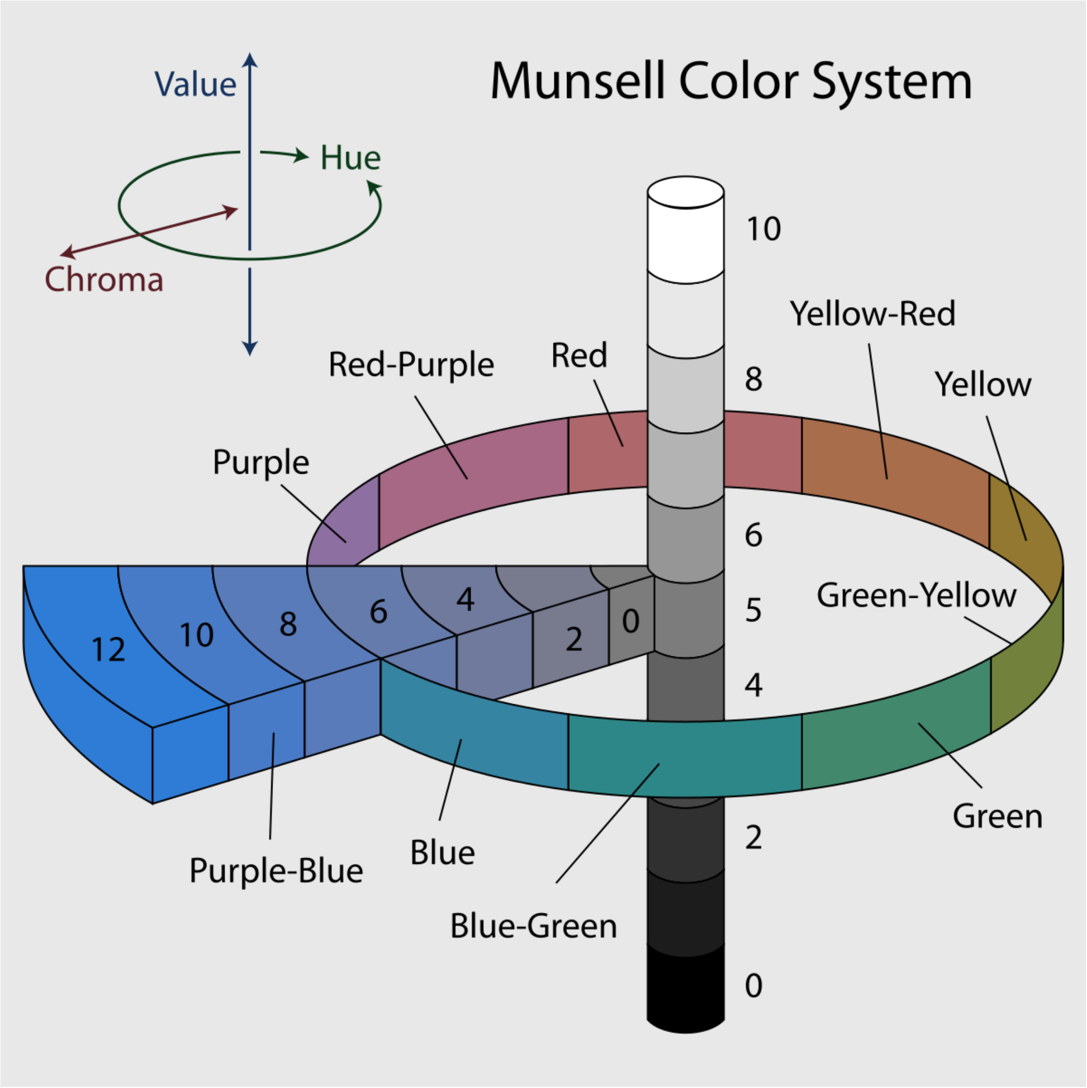
Principles of Color Technology Billmeyer and Saltzman second edition 1981

Color-Order System

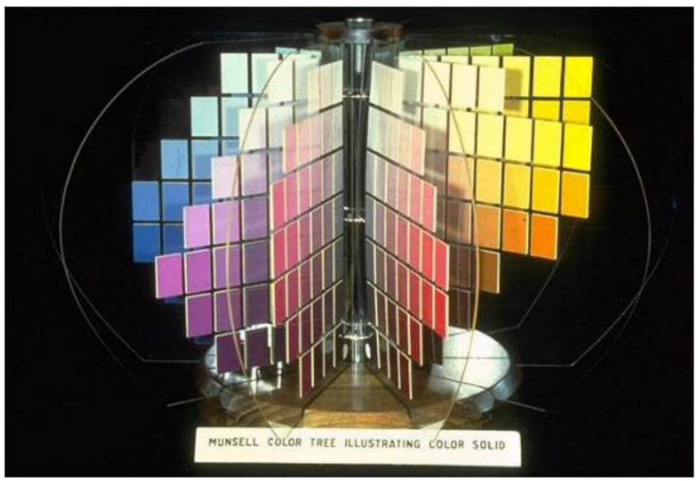
Munsell Book of Color

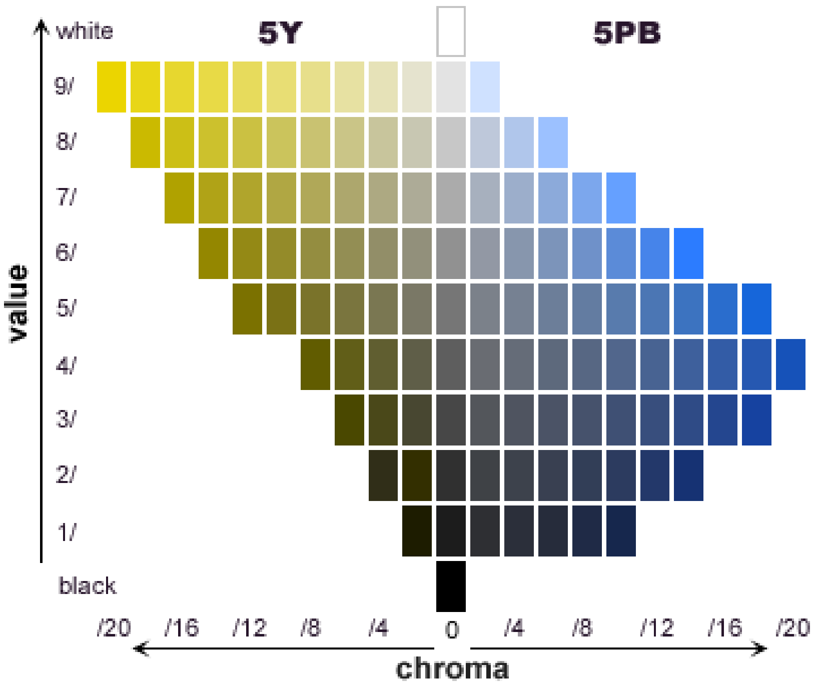
Color order system based on perception

Munsell Color System



Munsell Color System

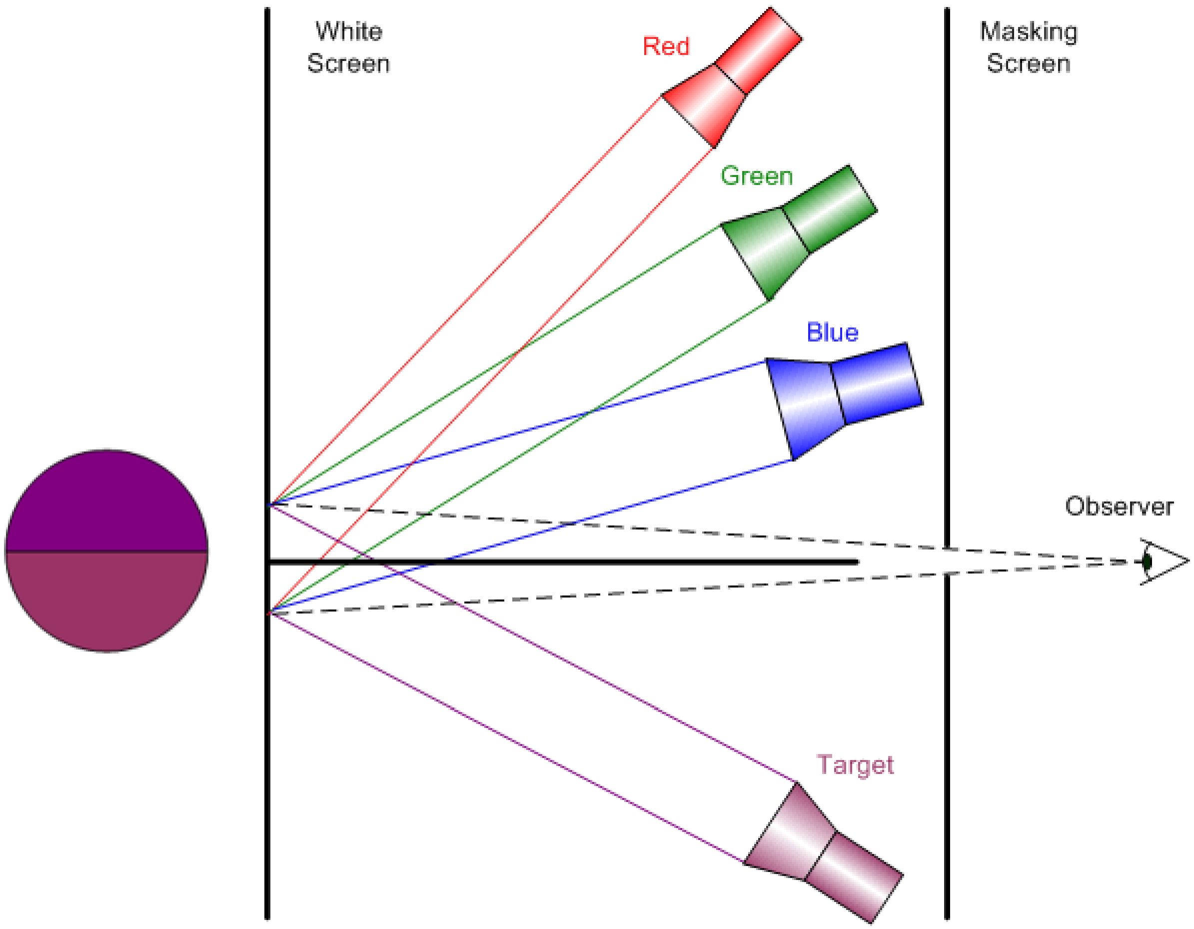




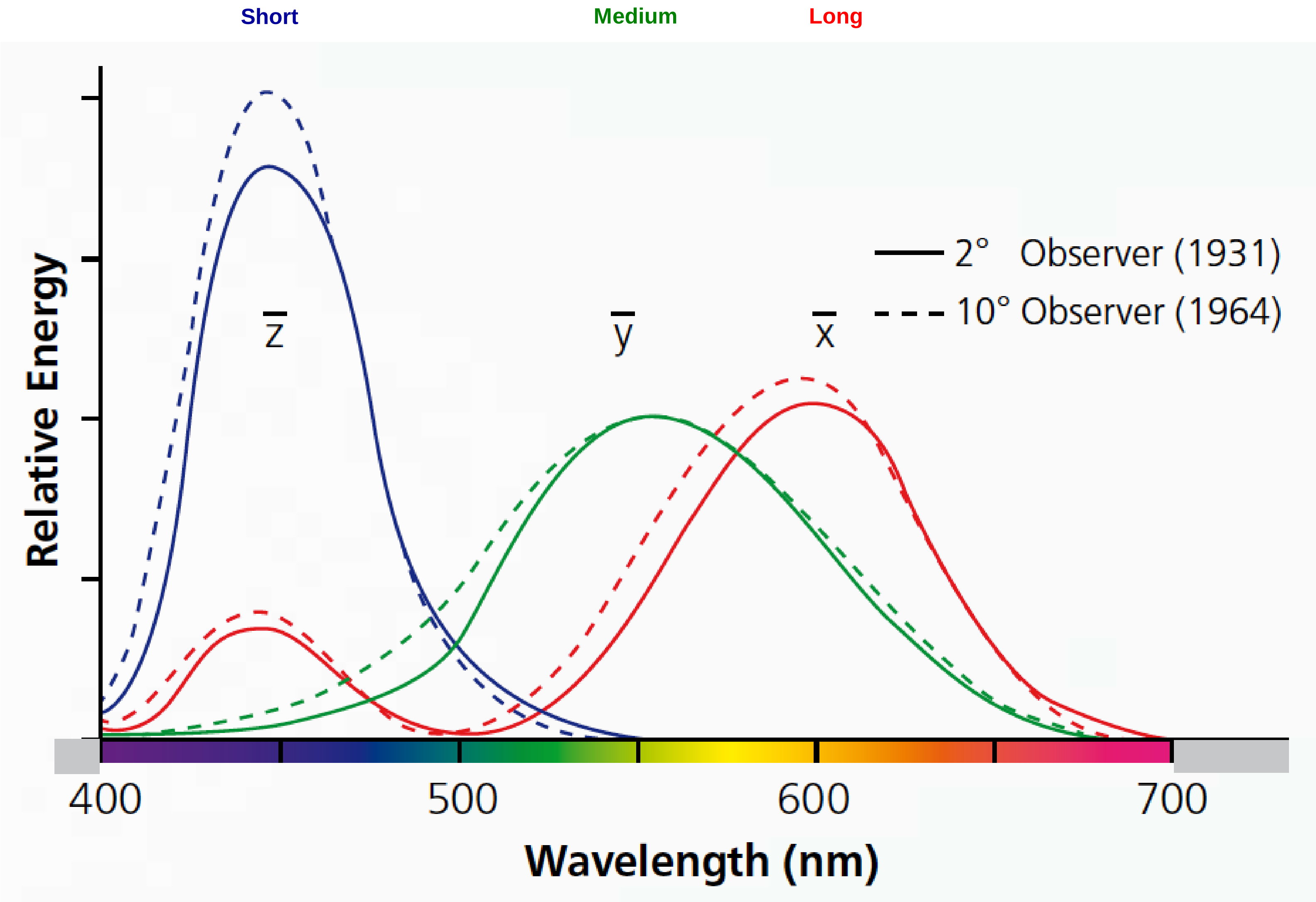
International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

Division 1: Vision and Colour
Division 2: Physical Measurement of Light and Radiation
Division 3: Interior Environment and Lighting Design
Division 4: Transportation and Exterior Applications
Division 6: Photobiology and Photochemistry
Division 8: Image Technology

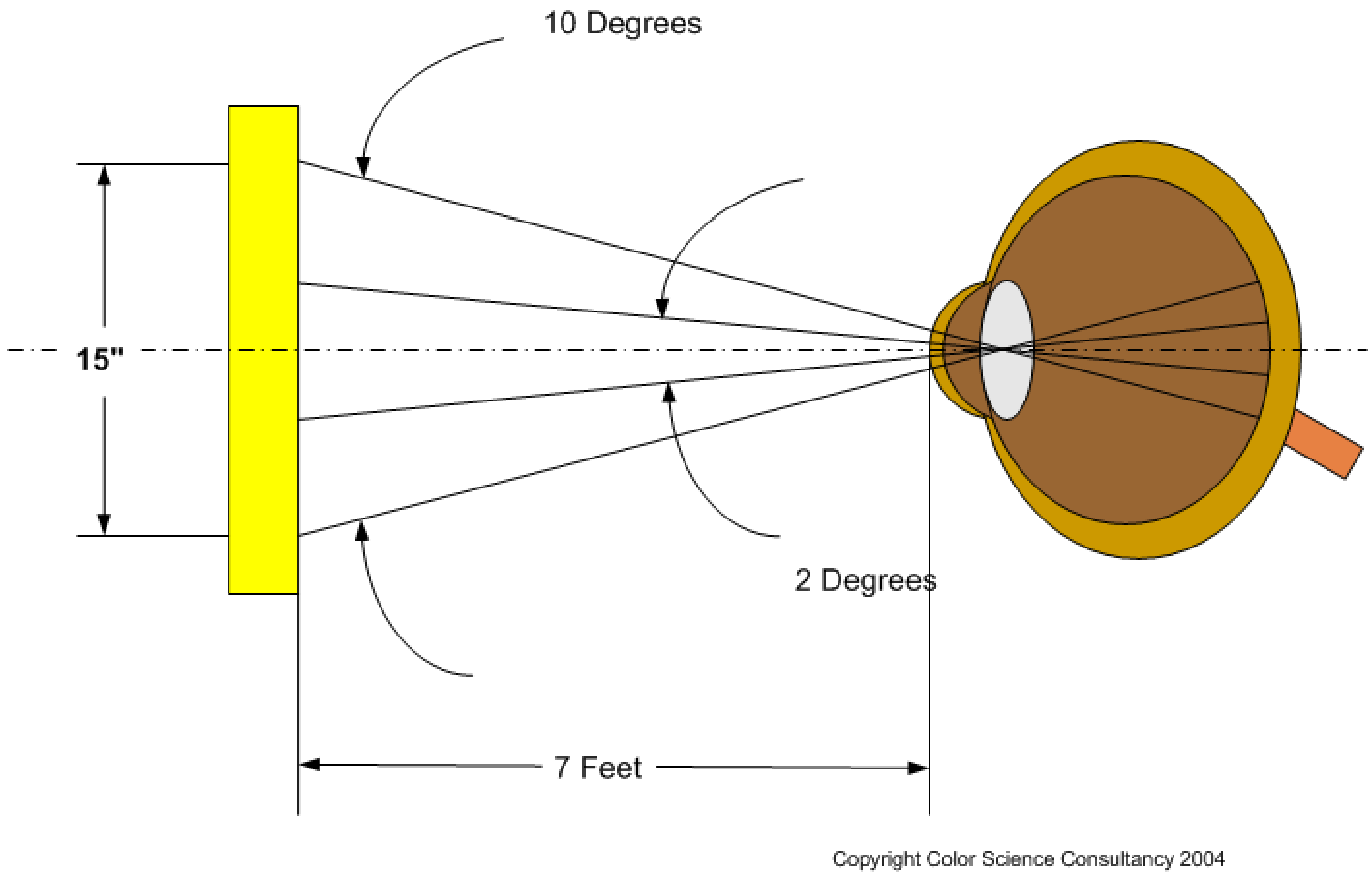
http://www.cie.co.at/



http://betterphotographytutorials.com



https://measurewhatyousee.com



1931 2º Observer
Field of View: ~ Ø 17mm @ 0.5M

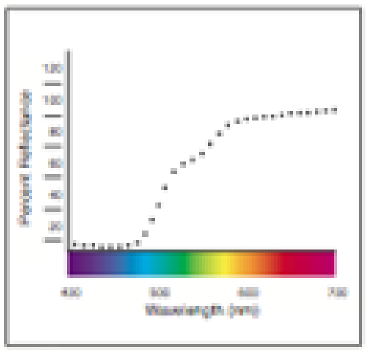
1964 10º Observer
Field of View: ~ Ø 90mm @ 0.5M

https://www.ledsmagazine.com/articles/print/volume-13/issue-8/features/packaged-leds/improving-color-consistency-in-led-based-general-lighting.html

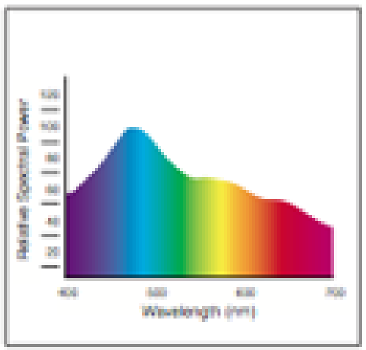
The Observer Functions

Wavelength λ (nm)	$\bar{x}(\lambda)$	$\bar{y}(\lambda)$	$\bar{z}(\lambda)$
380	0.0014	0.0000	0.0065
390	0.0042	0.0001	0.0201
400	0.0143	0.0004	0.0679
410	0.0435	0.0012	0.2074
420	0.1344	0.0040	0.6456
430	0.2839	0.0116	1.3856
440	0.3483	0.0230	1.7471
450	0.3362	0.0380	1.7721
460	0.2908	0.0600	1.6692
470	0.1954	0.0910	1.2876
480	0.0956	0.1390	0.8130
490	0.0320	0.2080	0.4652
500	0.0049	0.3230	0.2720
510	0.0093	0.5030	0.1582
520	0.0633	0.7100	0.0782
530	0.1655	0.8620	0.0422
540	0.2904	0.9540	0.0203
550	0.4334	0.9950	0.0087
560	0.5945	0.9950	0.0039
570	0.7621	0.9520	0.0021
580	0.9163	0.8700	0.0017
590	1.0263	0.7570	0.0011
600	1.0622	0.6310	0.0008
610	1.0026	0.5030	0.0003
620	0.8544	0.3810	0.0002
630	0.6424	0.2650	0.0000
640	0.4479	0.1750	0.0000
650	0.2835	0.1070	0.0000
660	0.1649	0.0610	0.0000
670	0.0874	0.0320	0.0000
680	0.0468	0.0170	0.0000
690	0.0227	0.0082	0.0000
700	0.0114	0.0041	0.0000
710	0.0058	0.0021	0.0000
720	0.0029	0.0010	0.0000
730	0.0014	0.0005	0.0000
740	0.0007	0.0002	0.0000
750	0.0003	0.0001	0.0000
760	0.0002	0.0001	0.0000
770	0.0001	0.0000	0.0000
780	0.0000	0.0000	0.0000

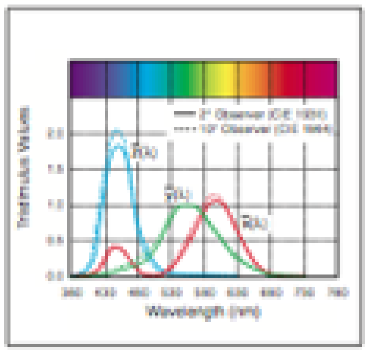
Reflectance Curve



X



X



=

X = 62.04
Y = 69.72
Z = 7.34

Spectral Reflectance Curves
table values

D65 Illuminant
table values

CIE Color Matching Functions
table values

Tristimulus Values

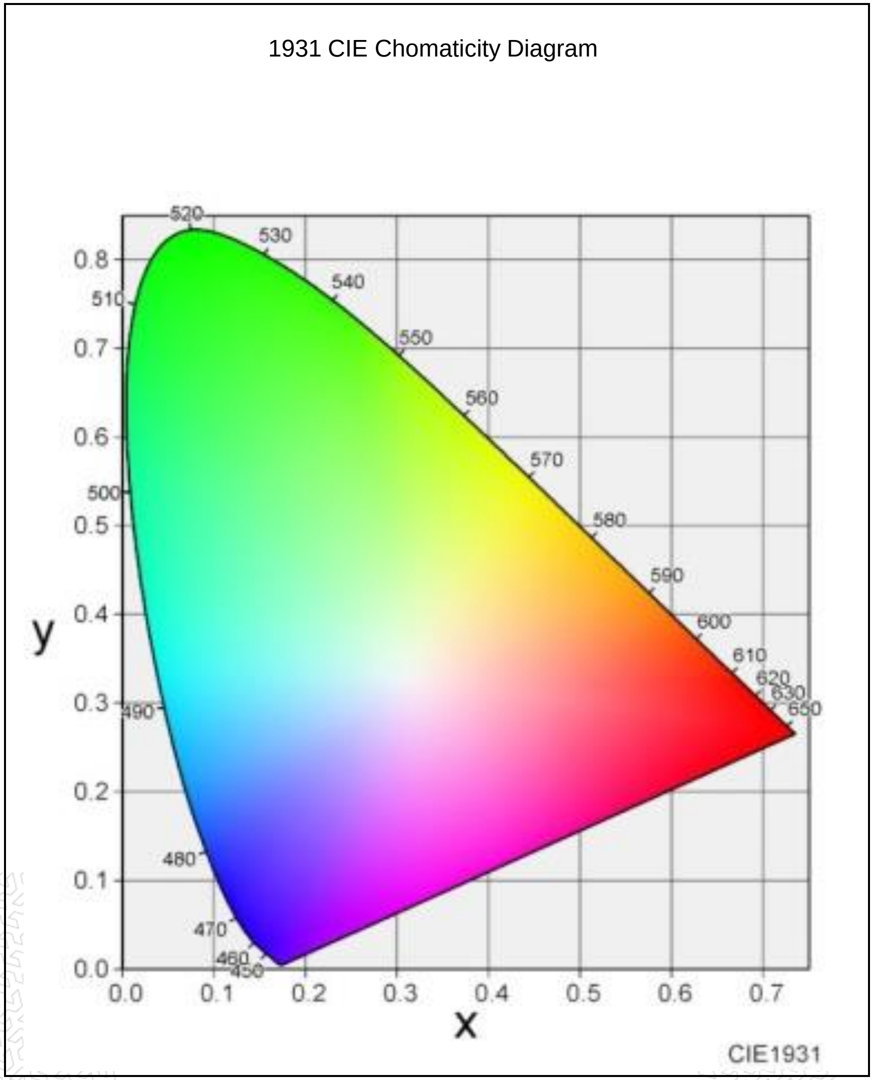
Calculating the Tristimulus Factors

CIE color-matching functions are defined from 360-830 nm in 1nm increments (ISO/CIE10527)

In practice, color computers are set up to measure 400-700nm

ASTM E 308 equations used to calculate the tristimulus values accommodate these outer regions by using precalculated tristimulus weighted values

By convention, for a reflecting object, the assigned value of Y=100 as maximum is used for a non-fluorescing white. There are no restricting maximum values for X and Z.



$$X = \frac{xY}{y}$$

$$Y = Y$$

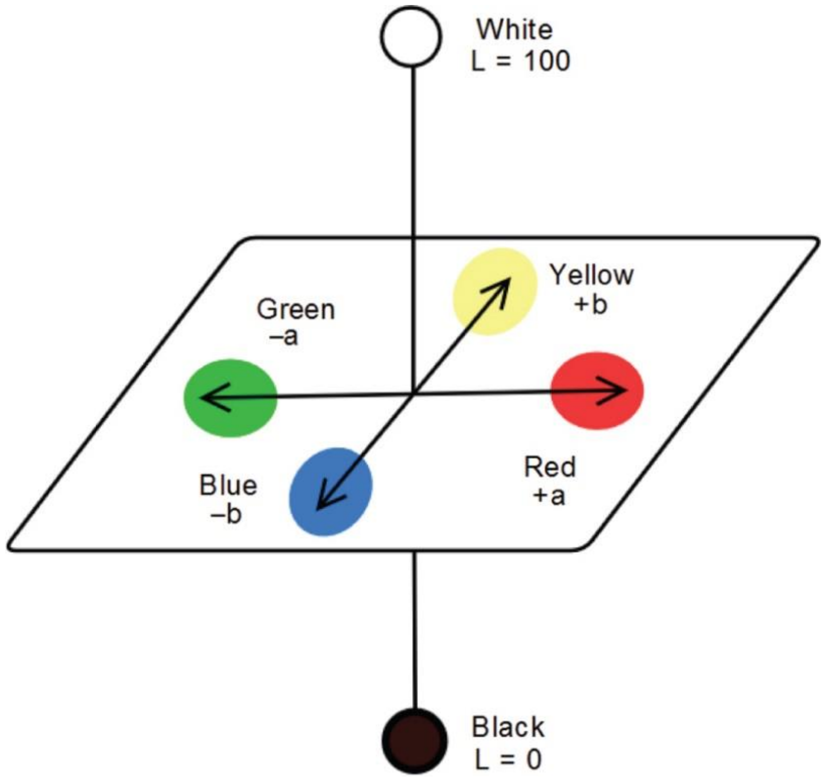
$$Z = \frac{(1 - x - y)Y}{y}$$

mplementation Notes:

1. Watch out for the case where $y = 0$. In that case, you may want to set $X = Y = Z = 0$.
2. The output (X, Y, Z) values are in the same nominal range as the input Y (typically, [0.0, 1.0], [0.0, 100.0] or physical units).

HUNTER Color Scale

Evolved during the 1950s and 1960s
More visually uniform color scale than the XYZ color scale (x,y,Y)
Hunter L, a, b color space is organized in a cube form



<u>Rectangular Coordinates</u>

L - Lightness
a - Red-Green
b - Yellow-Blue

HUNTER Equations

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

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

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

Differences or Deltas

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

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

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

+L	lighter	-L	darker
+a	redder	-a	greener
+b	yellower	-b	bluer

Total Difference or Delta

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

CIE Calculations (1976)

$$L^* = 116(Y/Y_n)^{1/3} - 16$$
$$a^* = 500[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}]$$
$$b^* = 200[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3})]$$

Cartesian or rectangular coordinates

$$C^* = [(a^*)^2 + (b^*)^2]^{1/2}$$
$$h^o = \arctan(b^*/a^*)$$

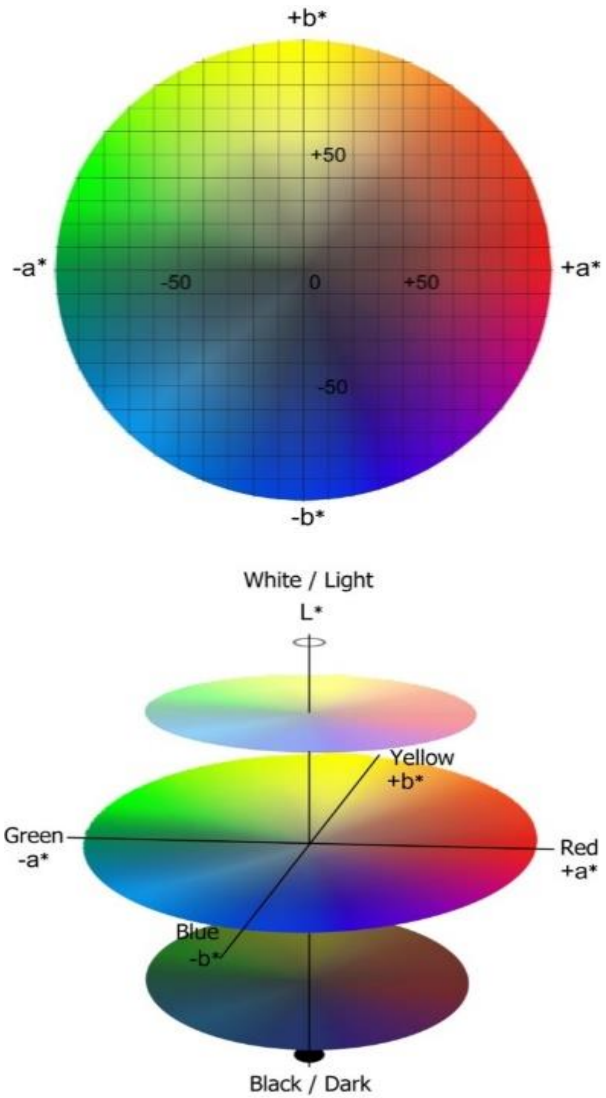
Polar coordinates

Use L-a-b when chroma <10 uniformly shaped description
Use L-C-h when chroma >10 metric hue numbers approach zero

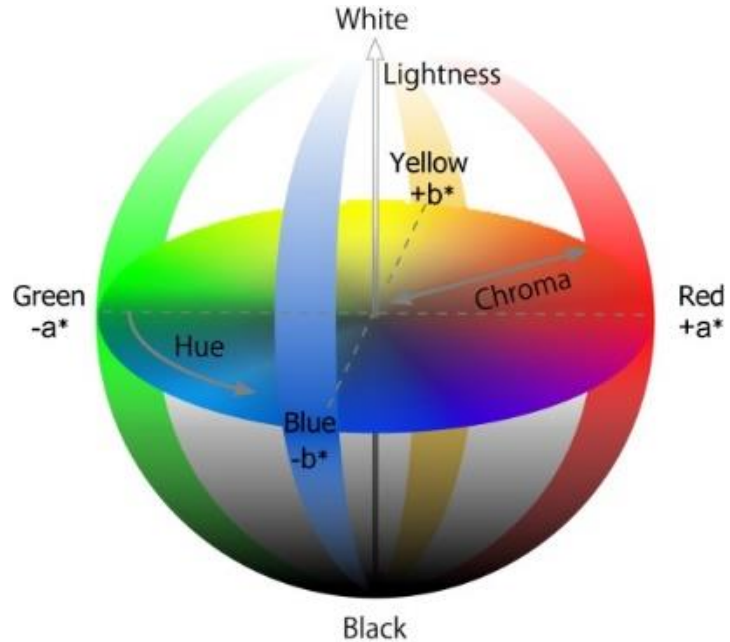
The asterisk (*) after L, a and b are pronounced star and are part of the full name, since they represent L*, a* and b*, to distinguish them from Hunter's L, a, and b

Section I – Color Science

The Image Descriptions of CIELAB

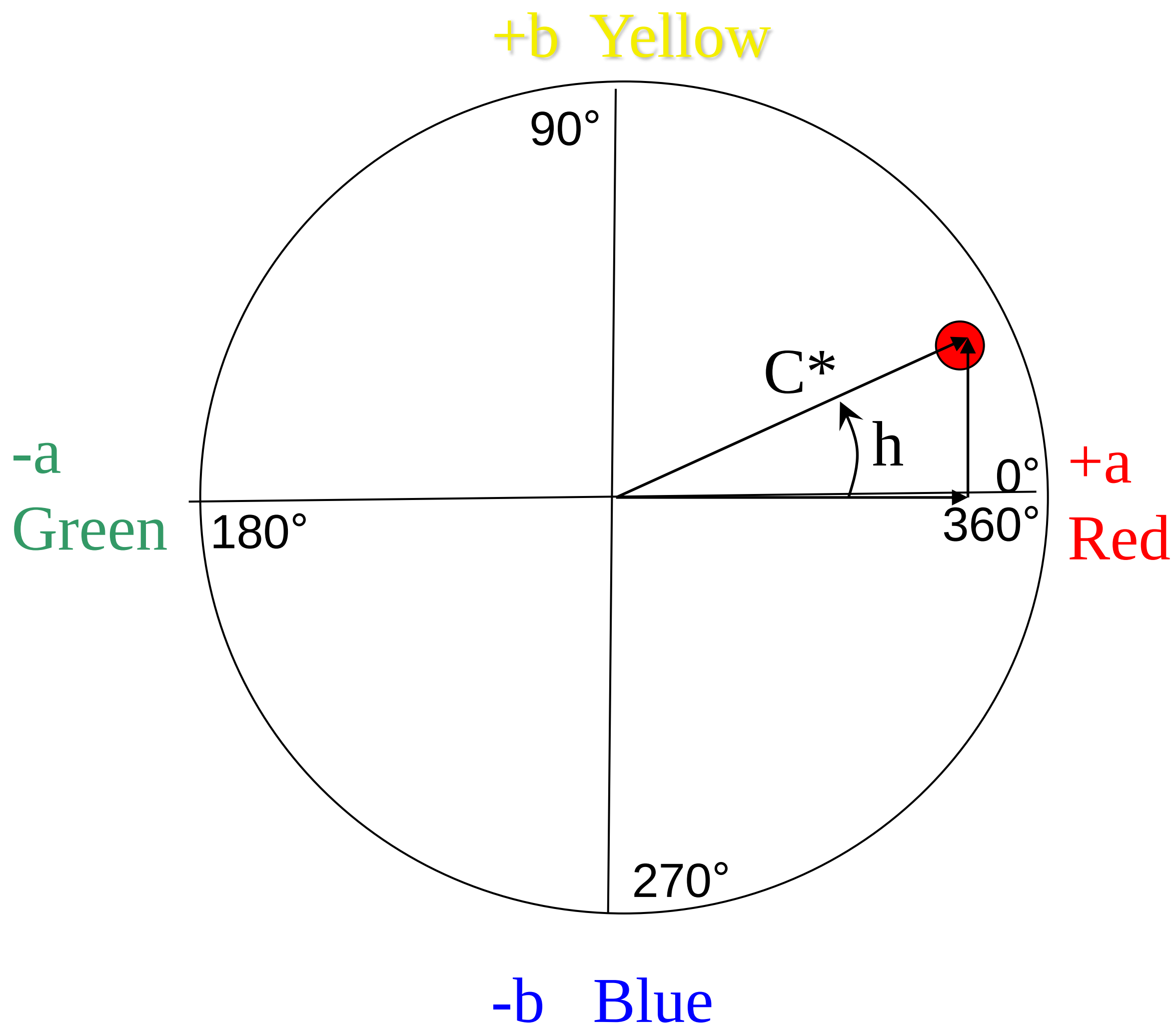


The Image Description of CIELCh



Color Guide by Ladson, Jack; and Kita, Hideo published by: SUGA Test Instruments Co., Ltd., Tokyo, Japan. "

CIELAB Color Space



Cylindrical Coordinates

L* - Lightness

C* - Chroma

h* - Hue angle

CIELab Color Difference Equations (Delta)

$$DL^* = L^*_{sample} - L^*_{standard}$$
$$Da^* = a^*_{sample} - a^*_{standard}$$
$$Db^* = b^*_{sample} - b^*_{standard}$$

$$DC^* = C^*_{sample} - C^*_{standard}$$
$$DH_{ab}^* = [(DE_{ab^*})^2 - (DL^*)^2 - (DC_{ab^*})^2]^{1/2}$$

Standard plaque

Sample plaque

L*a*b* Color Difference

ΔL* = +4.03
Δa* = -3.05
Δb* = +1.04
ΔE* = 5.16

L* = 43.31
a* = 47.63
b* = 14.12

Absolute color values
L-a-b

L* = 47.34
a* = 44.58
b* = 15.16

Absolute color values
L-a-b

Deltas (total color difference)

Strength values included for example 85% strength (K/S)

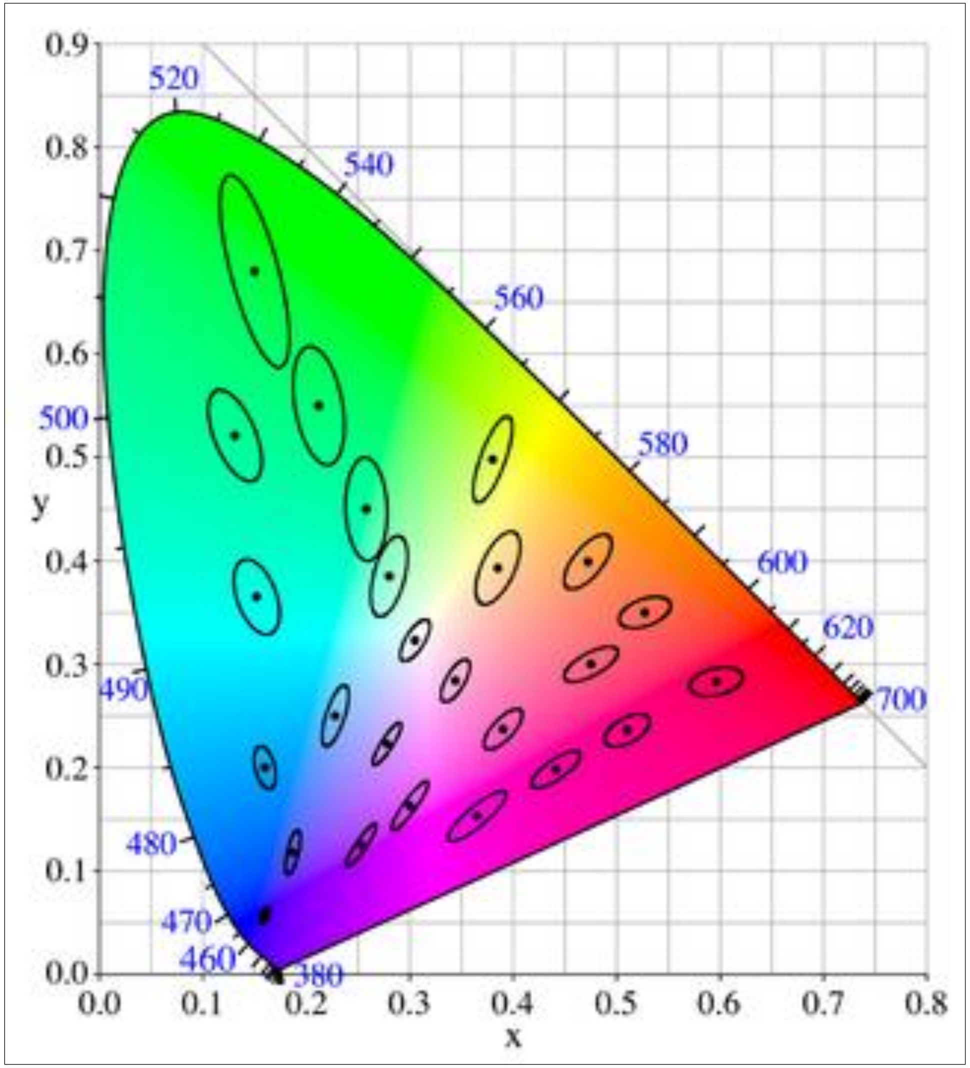
DE Total Color Difference

DE CIE 1976 Standard CIE color difference method, which is simply the distance between the two colors, calculated in three-dimensional CIELAB color space.

$$DE^* = [(DL^*)^2 + (Da^*)^2 + (Db^*)^2]^{1/2}$$

$$DE^* = [(DL^*)^2 + (DC^*_{ab})^2 + (DH_{ab}{}^*)^2]^{1/2}$$

McAdams Ellipses



Color Tolerance Equation

Color Measurement Committee (CMC)

UK Society of Dyers and Colourists → C.I. Numbers

DE CMC

ISO standard 105-J03, uses a *lightness weight* "l" and a *chroma weight* "c" for use with perceptibility data.

Originated in the textiles industry for varying surface textures

<u>l:c ratios for example</u>

1.3:1 for glossy surfaces and

2:1 for matte surfaces.

$$DE_{CMC(l:c)} = \left[\left[\frac{DL^*}{lS_L}\right]^2 + \left[\frac{DC^*}{cS_C}\right]^2 + \left[\frac{DH^*}{S_H}\right]^2 \right]^{1/2}$$

Color Tolerance Equation

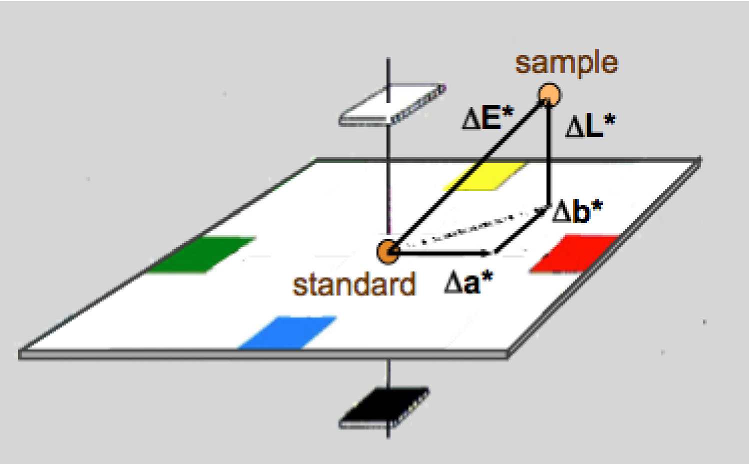
DE CIE 2000 Modification to the DE CIE 1976 with implementations $k_L = k_C = k_H = 1.0$

$$DE^*_{00} = \left[\left[\frac{DL'}{k_L S_L}\right]^2 + \left[\frac{DC'}{k_C S_C}\right]^2 + \left[\frac{DH'}{k_H S_H}\right]^2 + R_T \frac{DC'}{k_C S_C} \frac{DH'}{k_H S_H} \right]^{1/2}$$

Total Color Difference

Delta E* 1976

- DE* = 1
  - most observers can begin to detect a slight difference
- DE* = 2
  - Obvious differences to the majority of observers



https://measurewhatyousee.com/tag/tolerances/

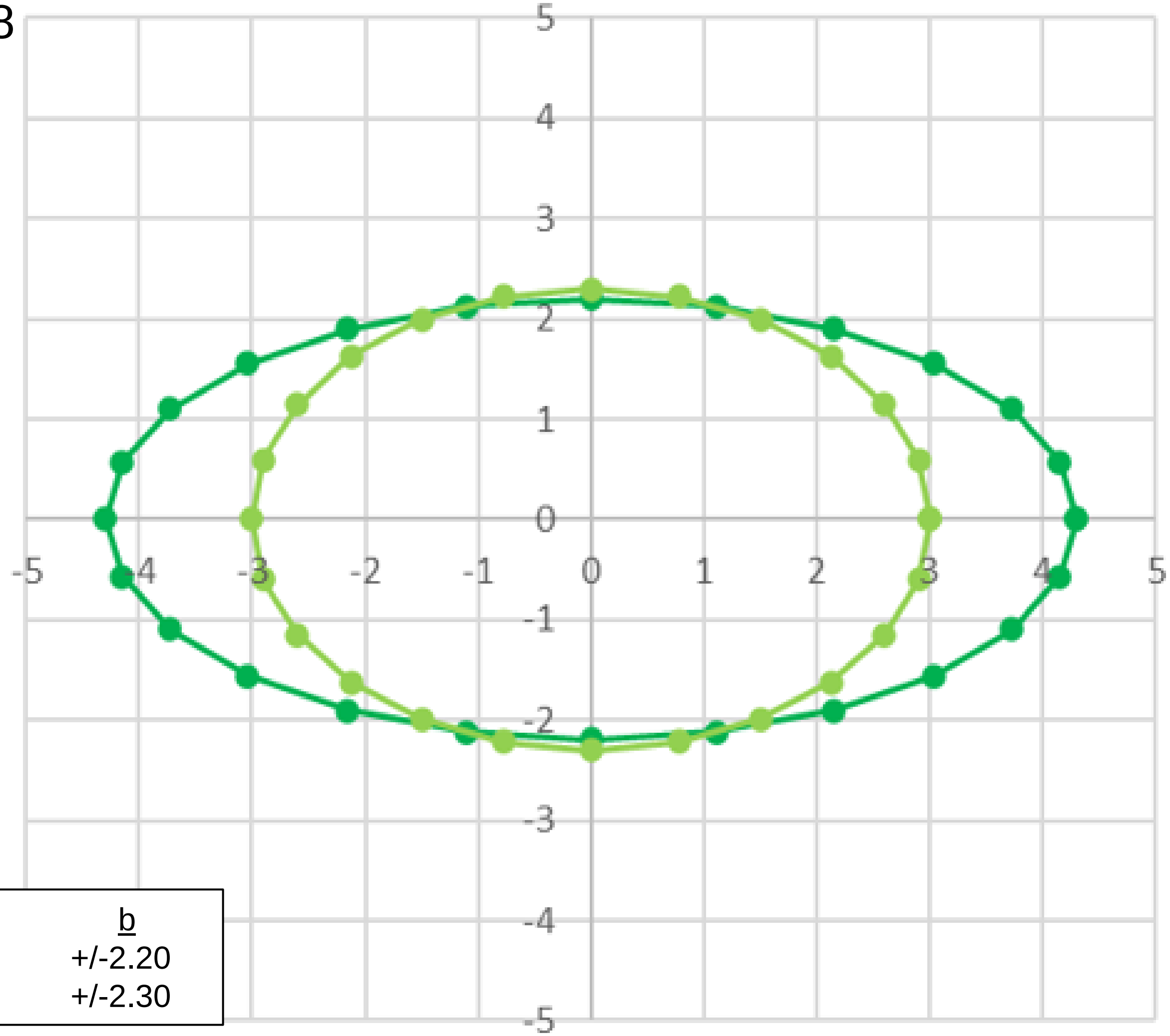
Color Tolerance Equations

- CMC DE_{cmc} = 1 (*Color Measurement Committee*)
  - Developed for the textiles industry
- CIELab DE^*_{2000} = 1
  - Current CIE recommended tolerance equation
  - 50% of trained color inspectors visually observe color differences

elliptical shaped specification

L = 90
a = -70
b = 8

GREEN



	a	b
DE2000	+/-4.30	+/-2.20
DEcmc	+/-3.00	+/-2.30

SPE COLOR & APPEARANCE

Standardization

Light Source

Spectral Power Distribution

Color Temperature

Standard Observer

Psychological dimensions of color (hue, saturation, brightness)

Unfiorm Color Space

International Commission on Illumination (CIELab)

Compare and Communicate Color Differences

End Section I – Color Science

Return to Index

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Credits

<u>Past Chairs/Contributors</u>

Robert Charvat, Colorants – Pigments and Dyes

Steve Goldstein, Inorganic - Organic Pigment Particles

Jack Ladson, Color Science Consultancy

Betty Puckerin, Ampacet Corporation

<u>Education Committee</u>

- Earl Balthazar, Datacolor
- Breeze Briggs, BASF Colors and Effects
- Steve Esker, Paramount
- Jack Ladson, Color Science Consultancy
- Bruce Mulholland, Celanese
- Alex Prosapio, Sudarshan
- Betty Puckerin, Ampacet Corporation
- Elizabeth Serdar, Omya
- Mark Tyler, Silberline
- Brian West, Techmer PM
- Kimberly Williamson, Techmer PM
- Michael Willis, Sun Chemical, ***Education Committee Chair***