datacolor Academy

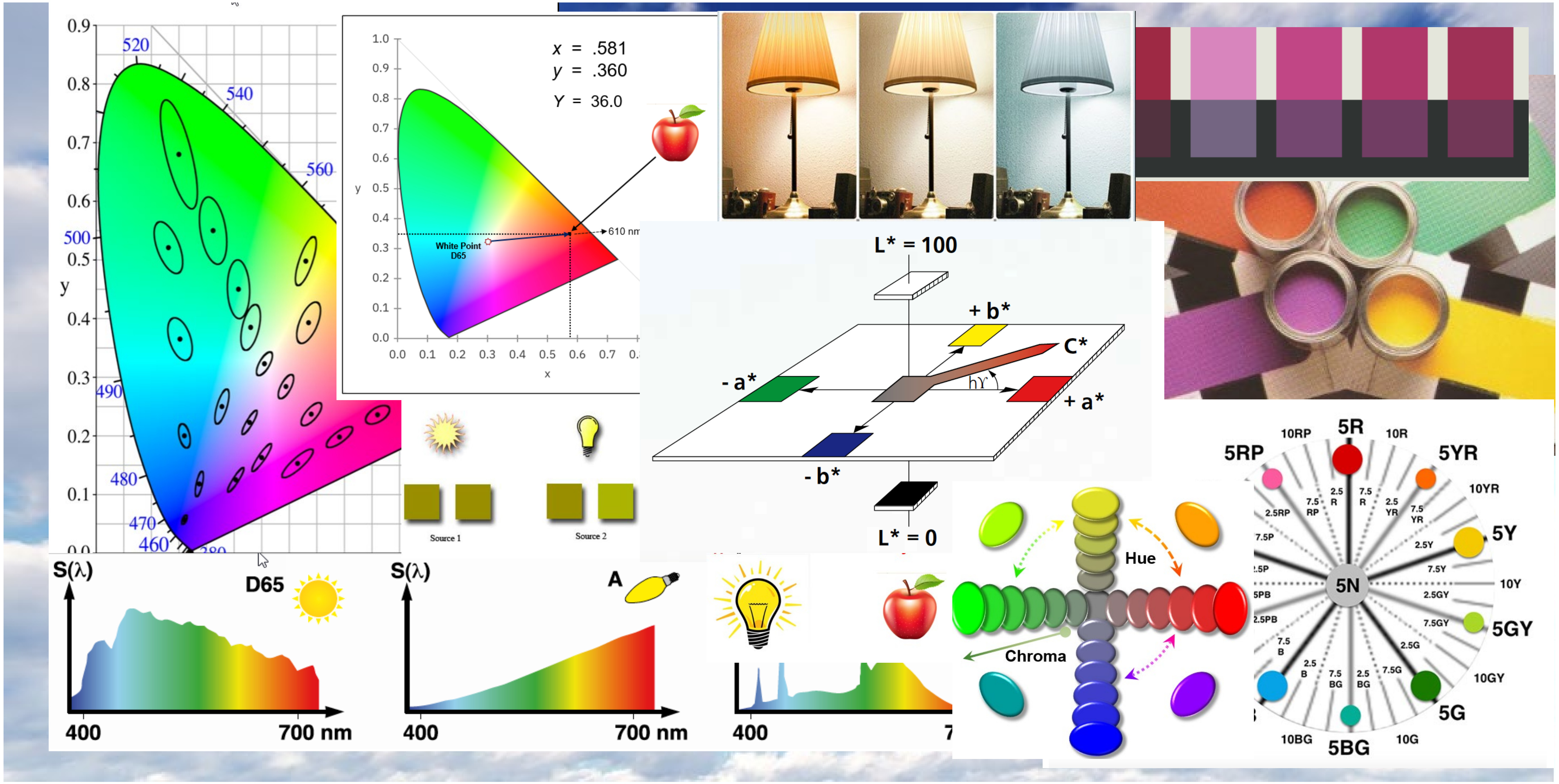
Color Theory – Part 3

Color Coordinates

Color Theory – Part 3

Color Coordinates

datacolor Academy

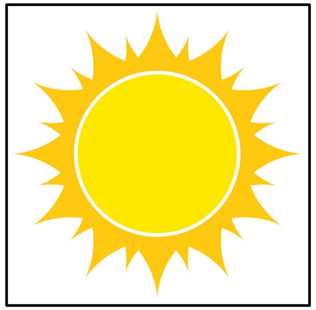


Review

Color Perception versus Color Description

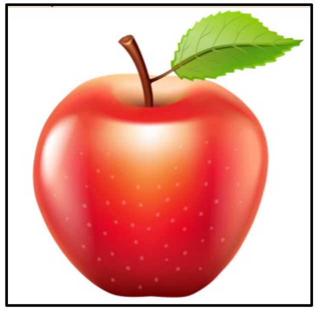
datacolor Academy

We have described the visual color perception process by showing how the light source, object and observer are together responsible for color perception.



Light Source

x



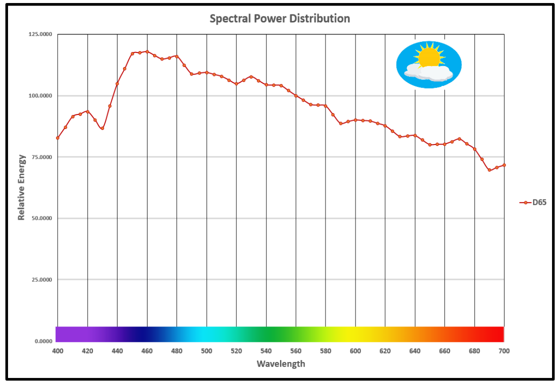
Object

x

Observer

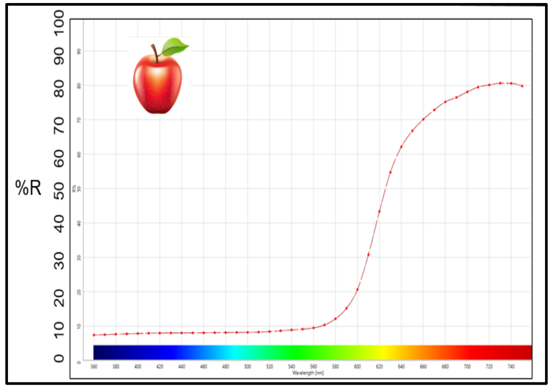
= **Color Perception**

With the Standard Observer, we can now develop a numerical specification:



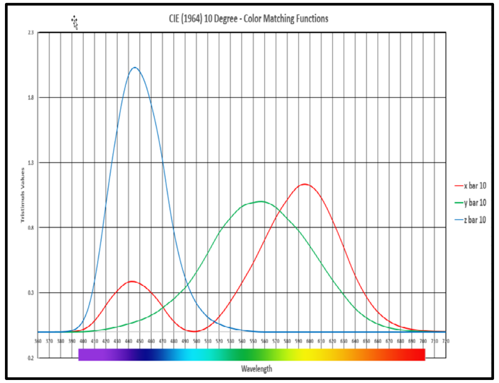
Daylight Illuminant Numerical Data

x



Reflectance Curve Numerical Data

x



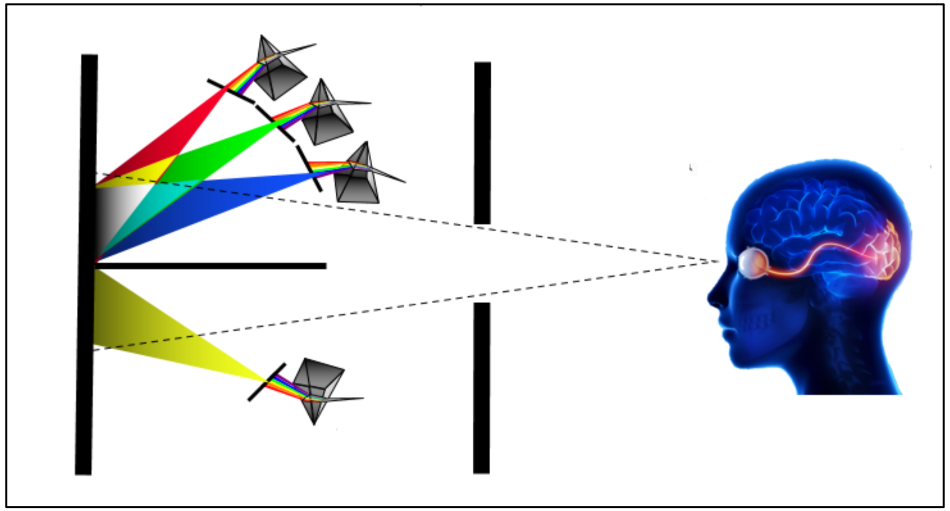
CIE Standard Observer Numerical Data

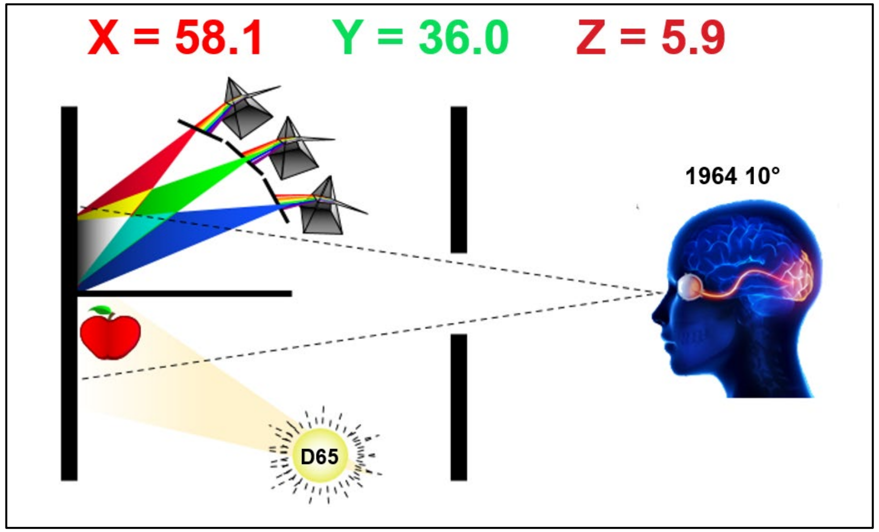
= **Colorimetric Description**

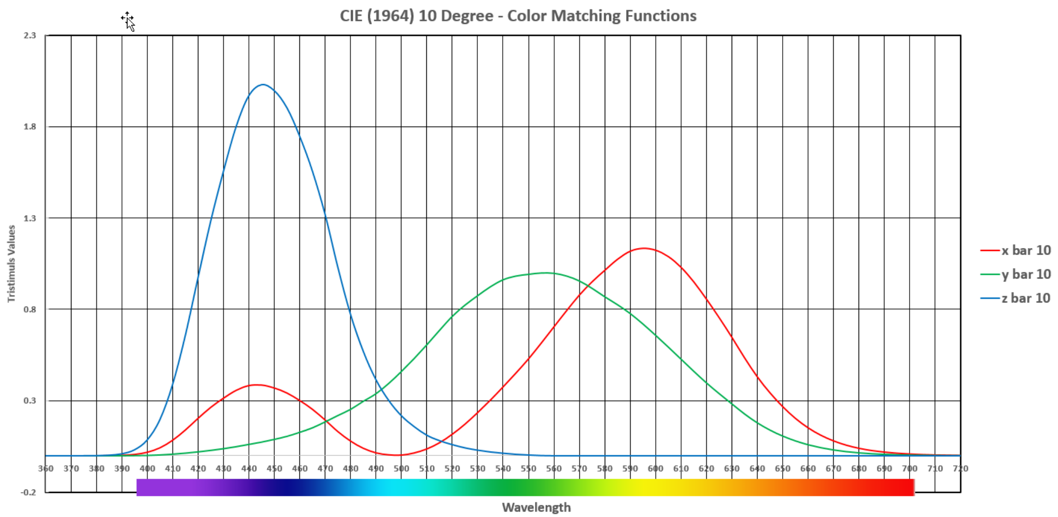
Review

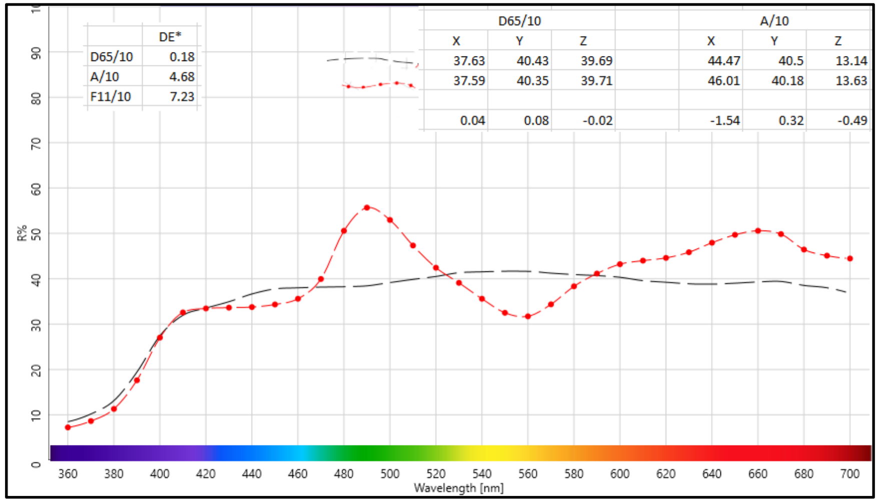
Standard Observer / Metamerism

datacolor
Academy





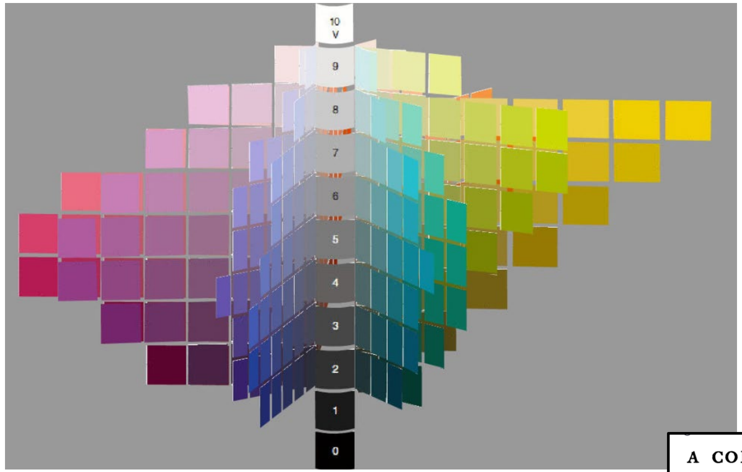


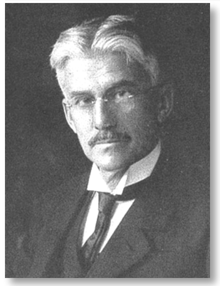


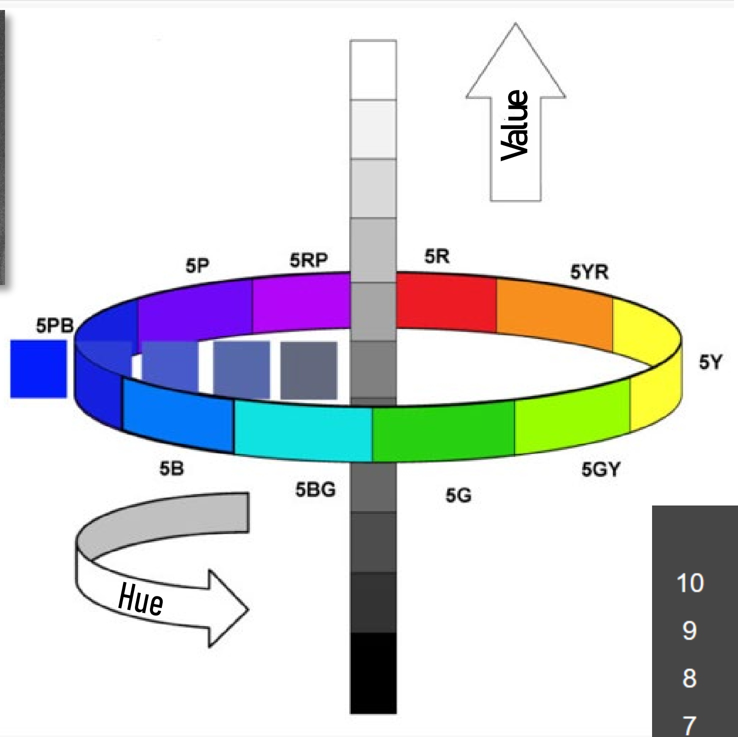
Color Order Systems

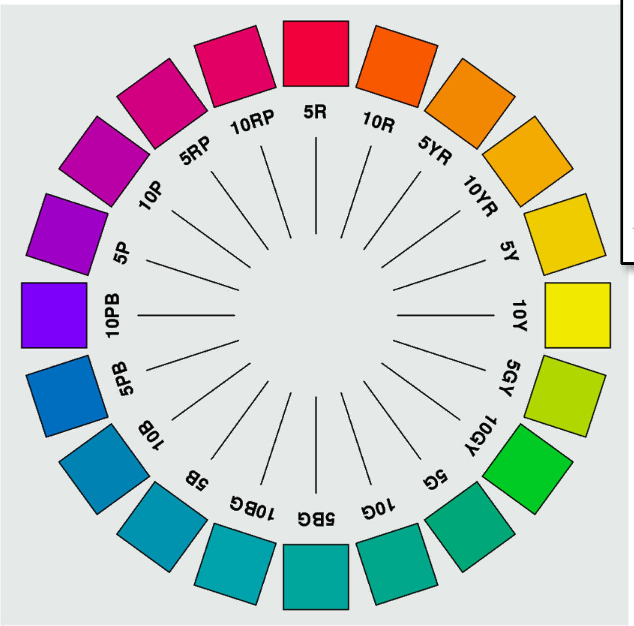
Munsell - A Visual System

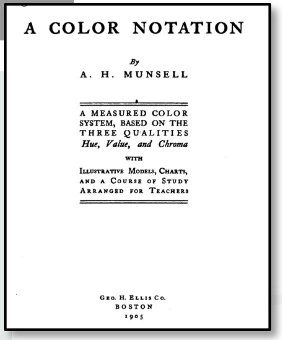
datacolor Academy











A COLOR NOTATION

By

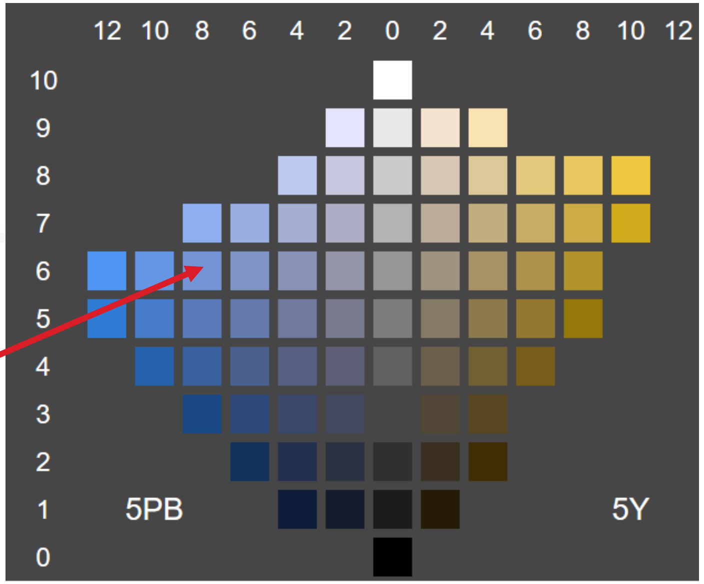
A. H. MUNSELL

A MEASURED COLOR SYSTEM, BASED ON THE THREE QUALITIES *Hue, Value, and Chroma*

WITH

ILLUSTRATIVE MODELS, CHARTS, AND A COURSE OF STUDY ARRANGED FOR TEACHERS

GEO. H. ELLIS CO.
BOSTON
1905



Munsell Notation:

5PB 6/8

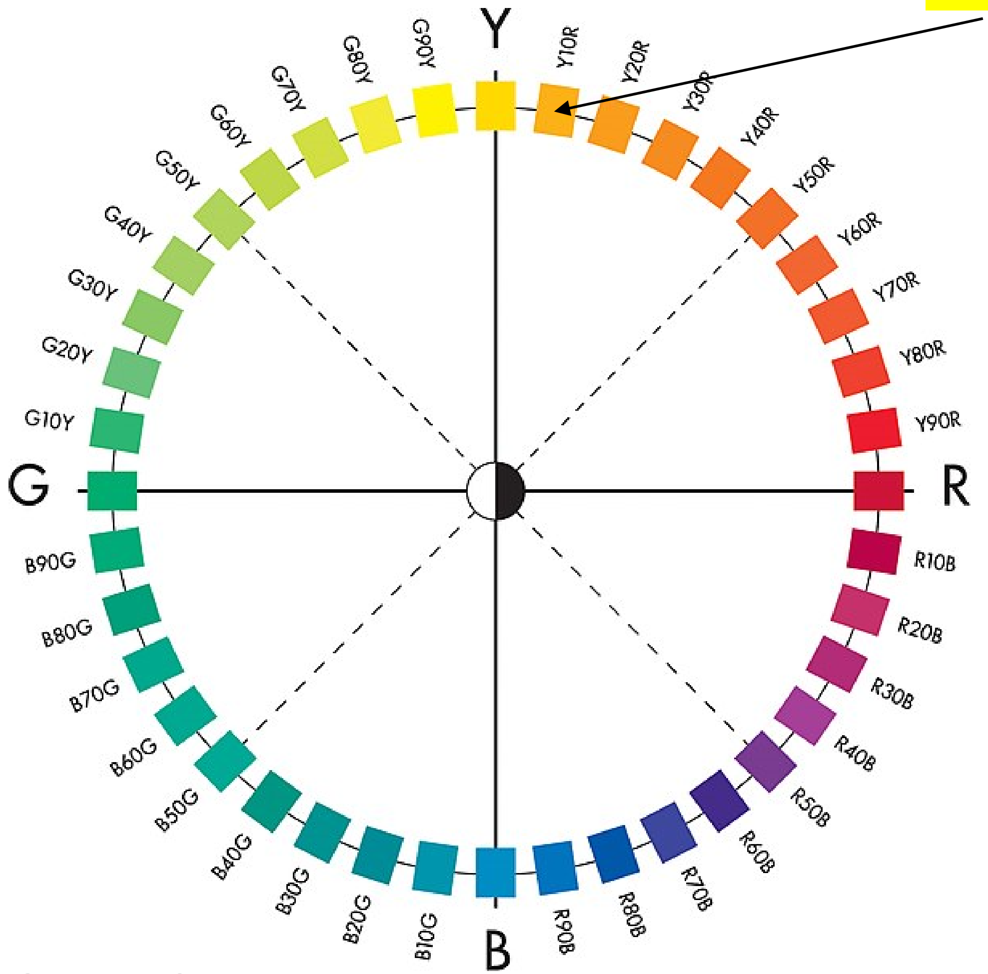
Hue Value/Chroma

NCS

Natural Color System - Opponent Color Model

Datacolor Academy

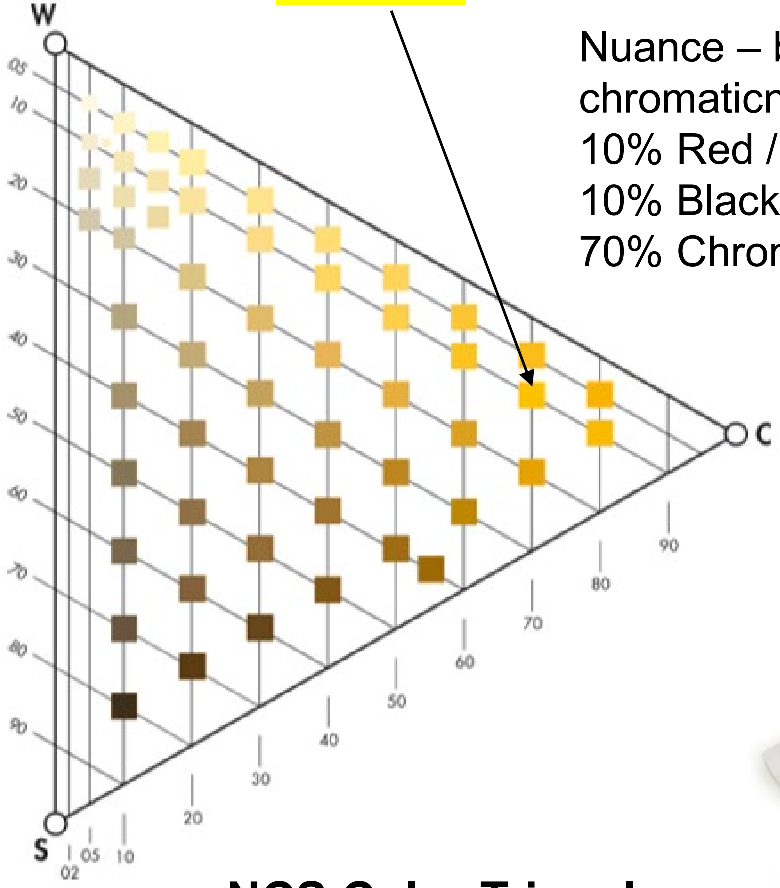
S 1070-Y10R



NCS Hue Circle

S 1070-Y10R

Nuance – blackness and chromaticness of a color.
10% Red / 90% Yellow
10% Blackness
70% Chromaticness



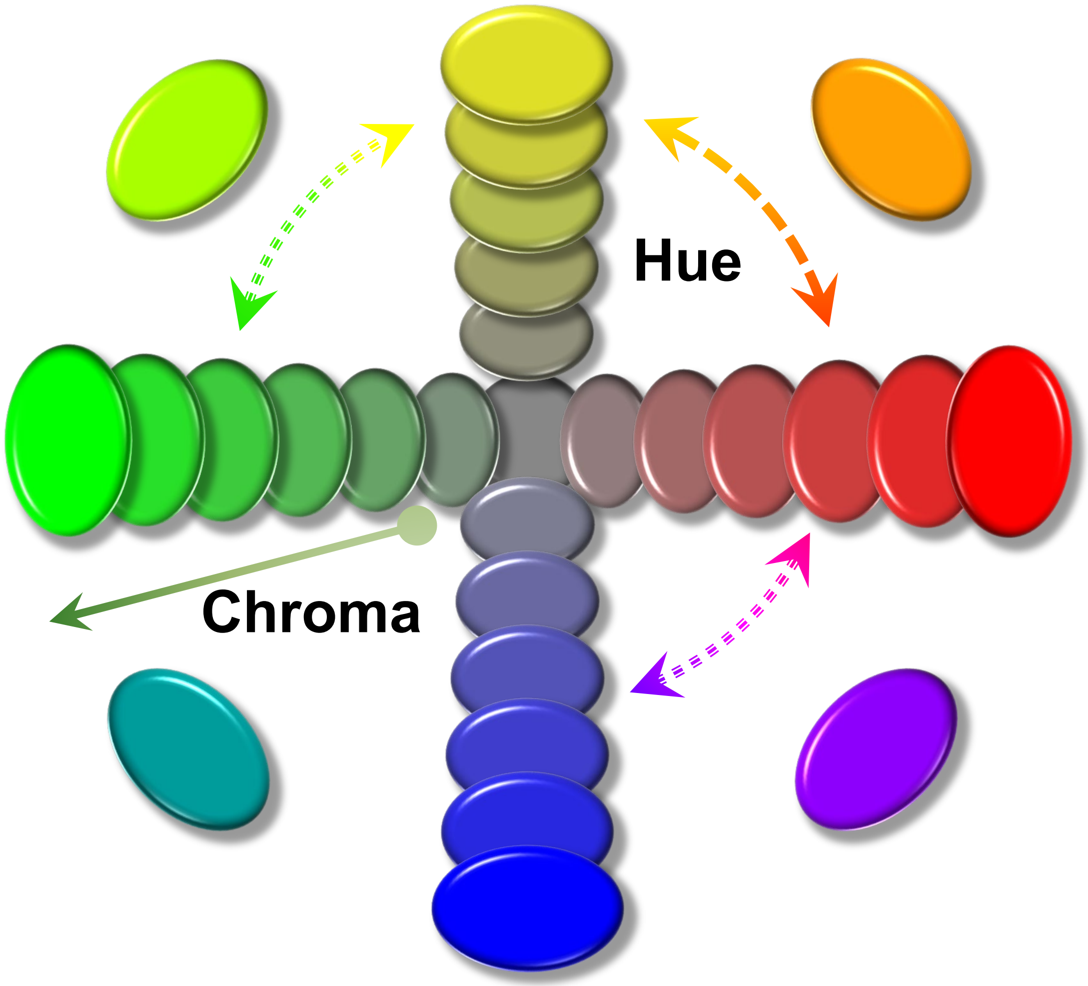
NCS Color Triangle

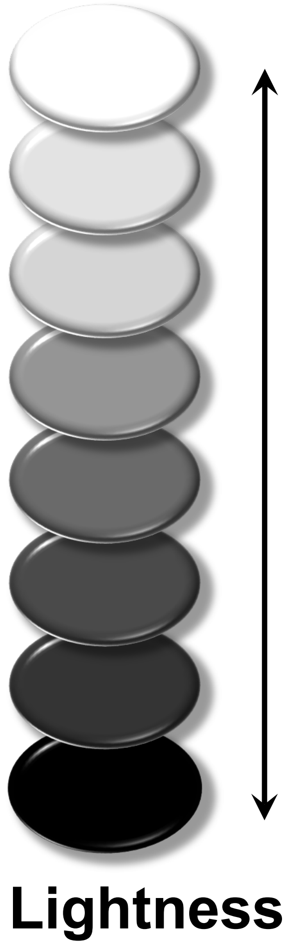
NCS 1950 Index

3 Dimensions of Color

Hue, Chroma, Lightness

Academy





Hue is the term we use to describe a specific color like yellow, red, blue, green, violet.

Chroma is the amount or intensity of a specific hue. The saturation or difference from gray.

Lightness is the total amount of light coming from a sample independent of hue and chroma.

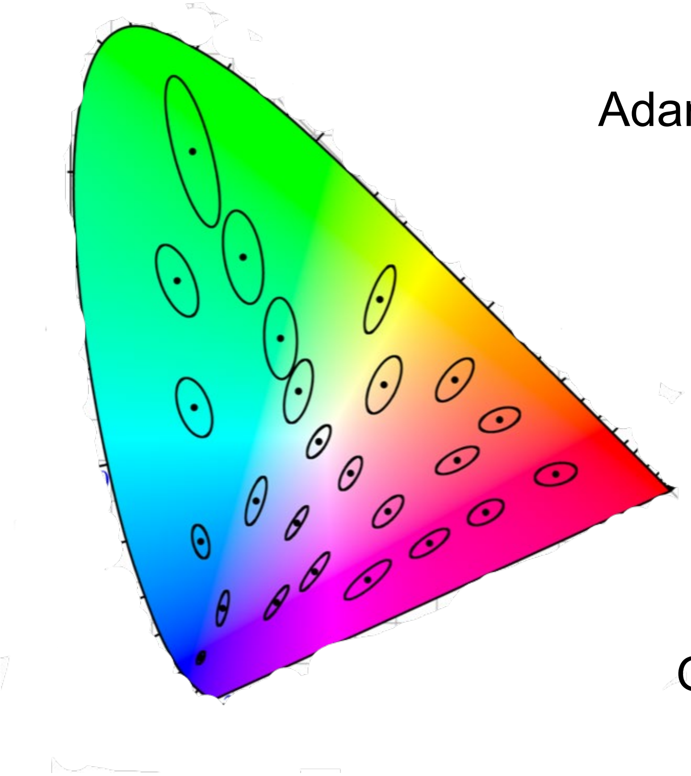
CIELAB

Non-linear Transformation of CIE xyY Color Space

CIE 1976

CIE L*a*b*

CIE xyY

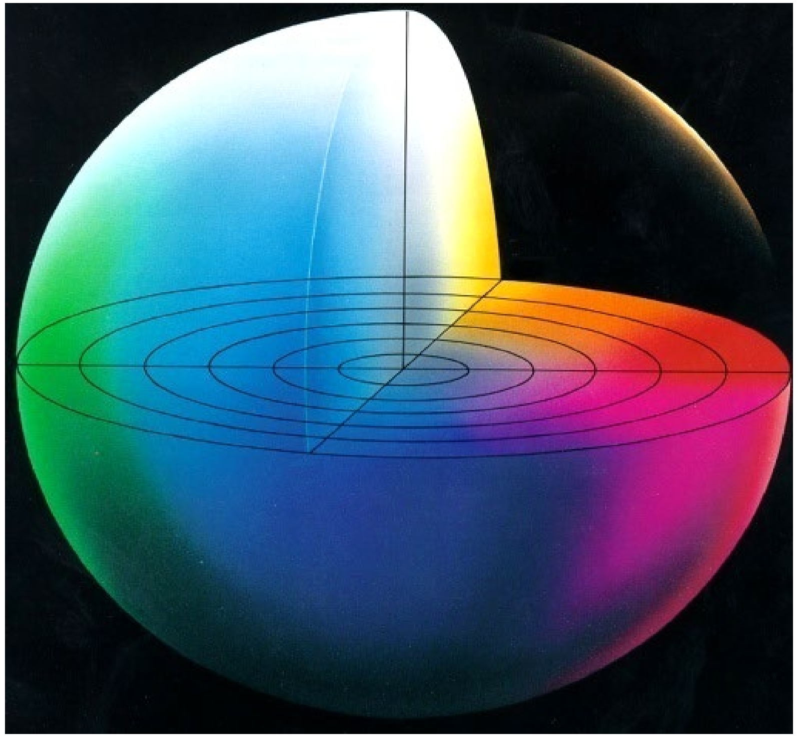


Munsell System

Adams Chromatic Value
1942

Adams-Nickerson
ANLab
1944, 1950

Glasser –Reilly
Cube Root
1958

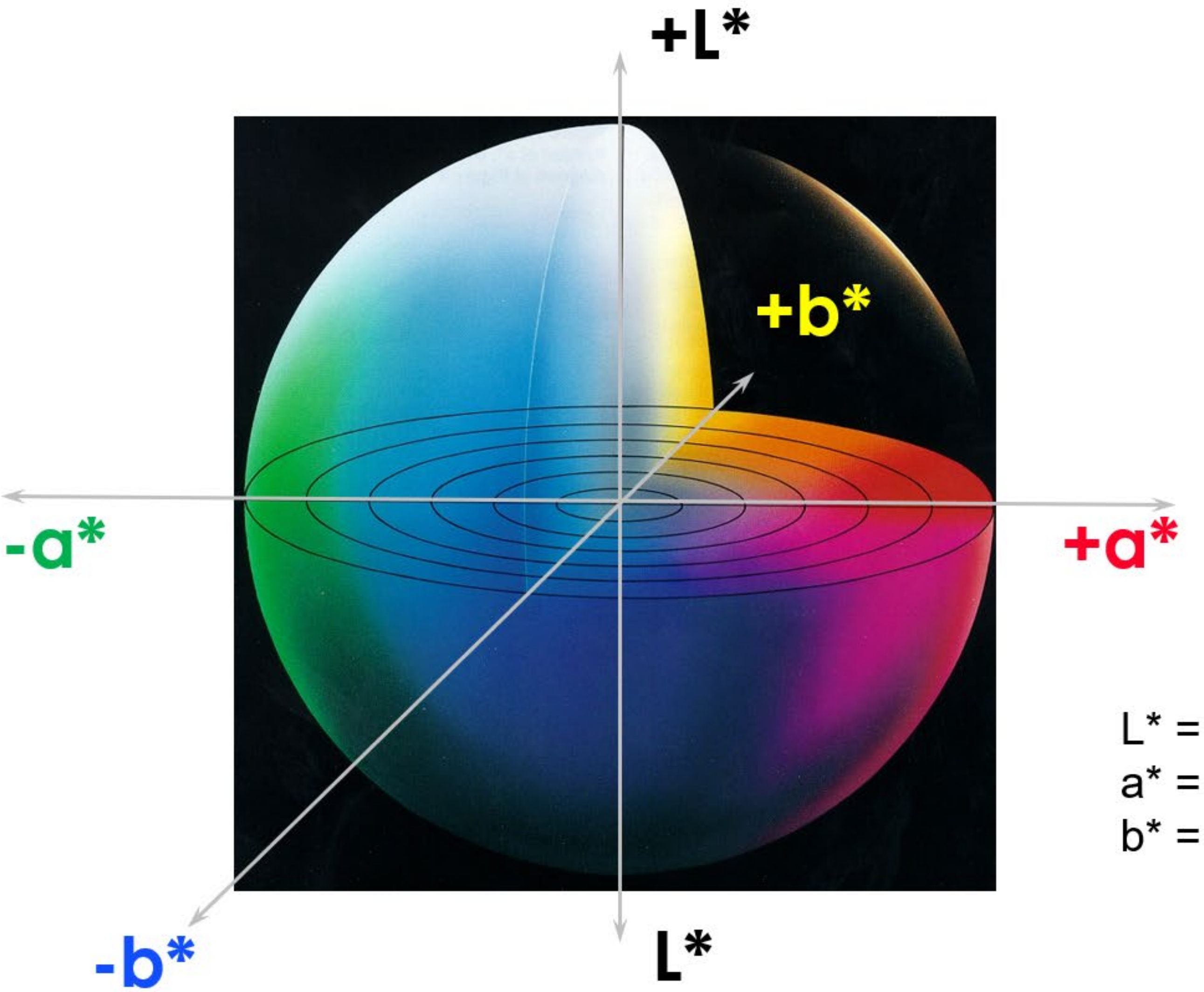


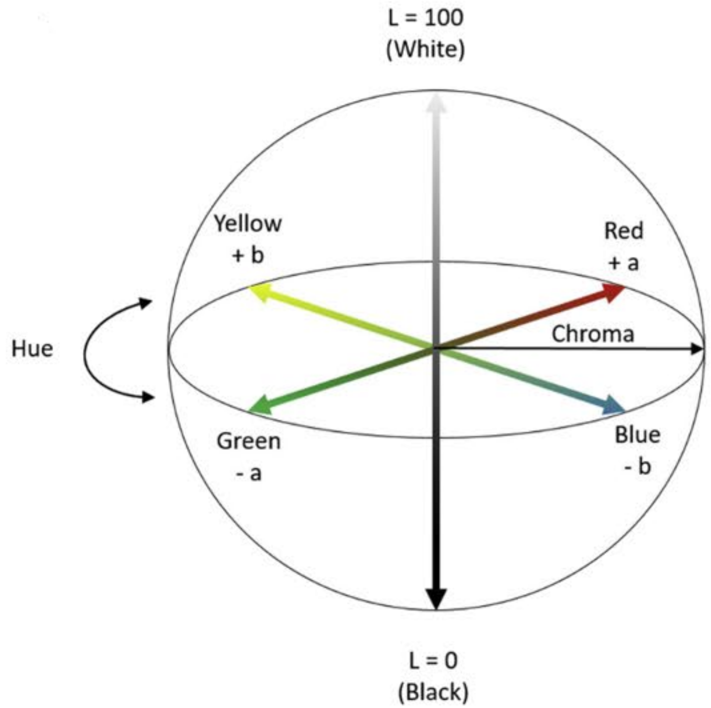
Opponent Color Model

CIELAB

*CIE L*a*b* Color Space*

datacolor Academy



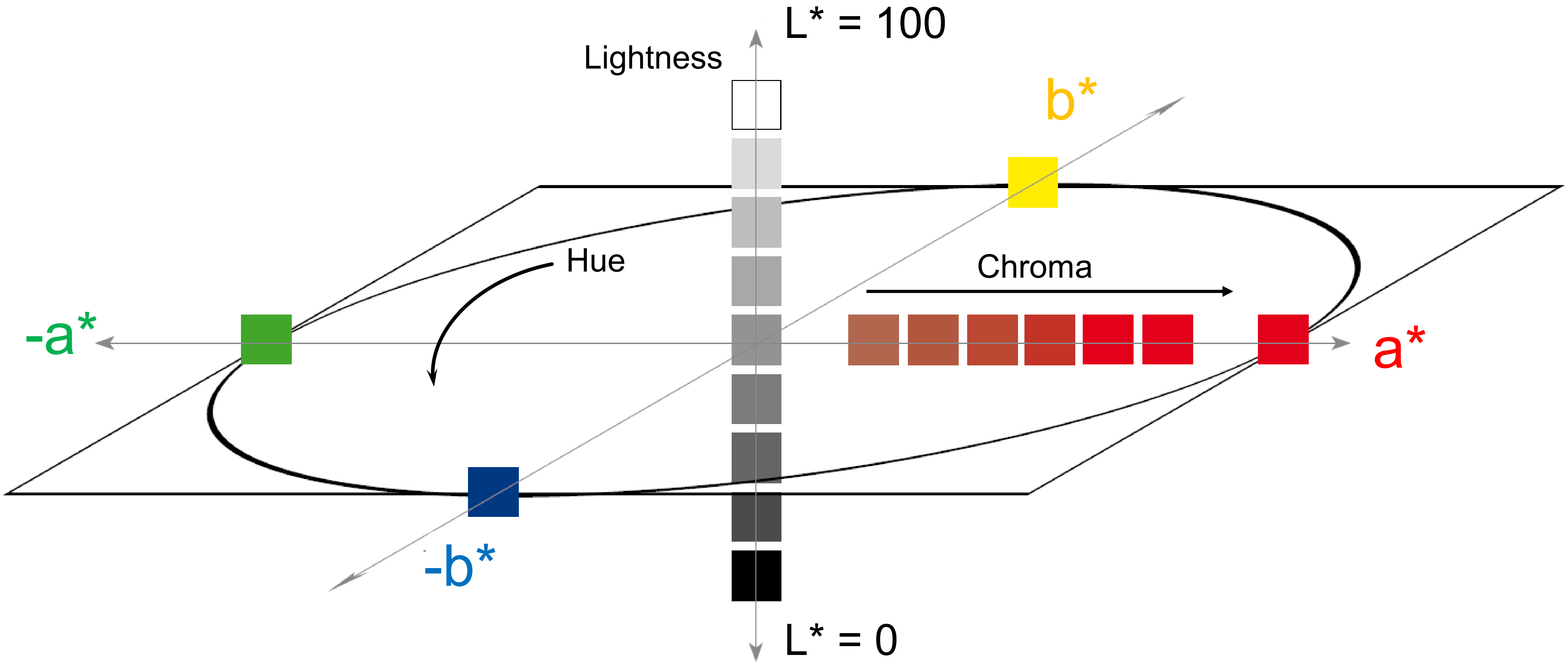


L* = Lightness
a* = red-green axis +a* (red) -a* (green)
b* = yellow-blue axis +b* (yellow) -b* (blue)

Opponent Color Model

CIELAB

*CIE L*a*b* Color Space*

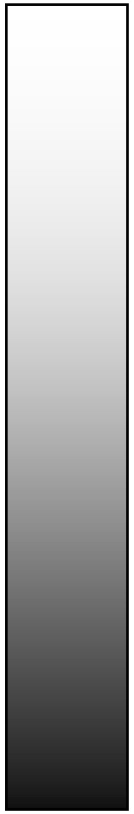


CIELAB Equations

L , Lightness - Darkness*

Datacolor Academy

L* = 100 White

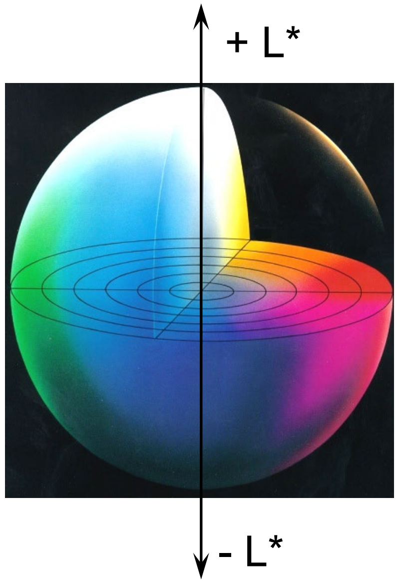


L* = 0 Black

$$L^* = 116\,(Y/Y_n)^{1/3} - 16$$

Y_n = Tristimulus Value of White
Valid for Y/Y_n > or = 0.01

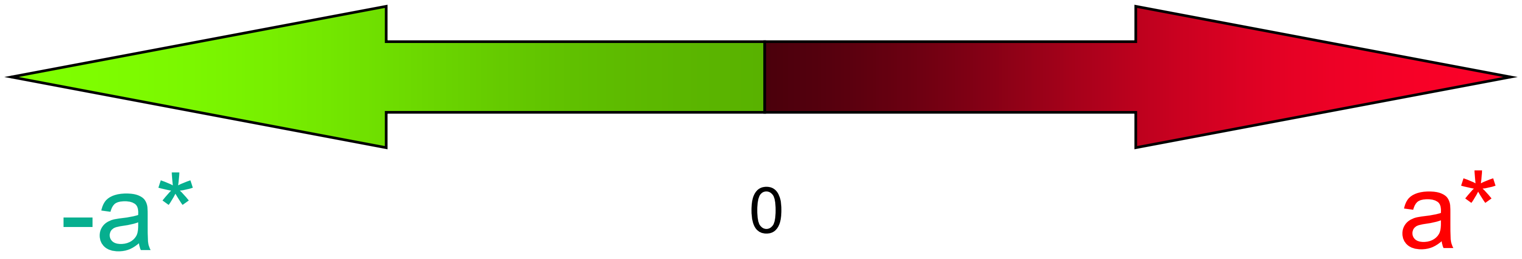
$X_n = 94.81$; $Y_n = 100.0$; $Z_n = 107.3$ For D65/10

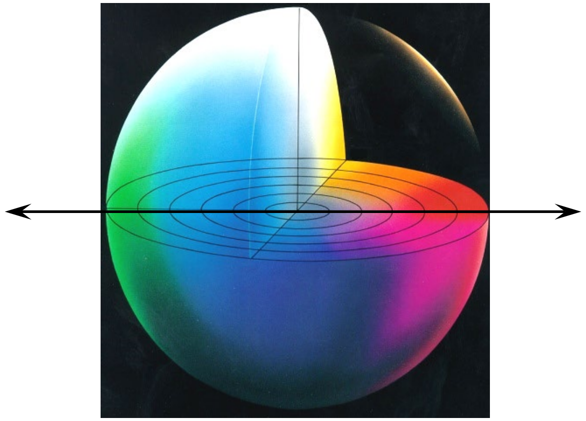


CIELAB Equations

a , red - green*

datacolor Academy





$$a^* = 500\,(X/X_n)^{1/3} - 500\,(Y/Y_n)^{1/3}$$

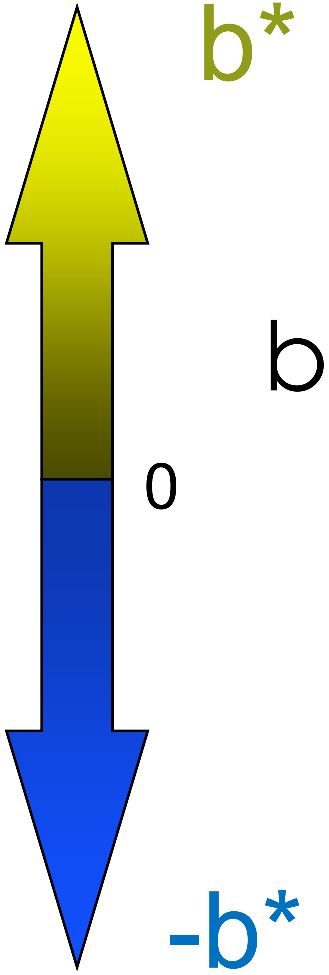
Valid for X/X_n & Y/Y_n > or = 0.01

$X_n = 94.81$; $Y_n = 100.0$; $Z_n = 107.3$ For D65/10

CIELAB Equations

b , yellow - blue*

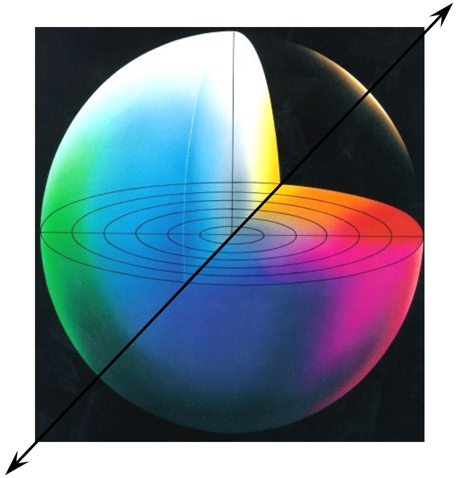
datacolor Academy



$$b^* = 200\,(Y/Y_n)^{1/3} - 200\,(Z/Z_n)^{1/3}$$

Valid for Z/Z_n & Y/Y_n > or = 0.01

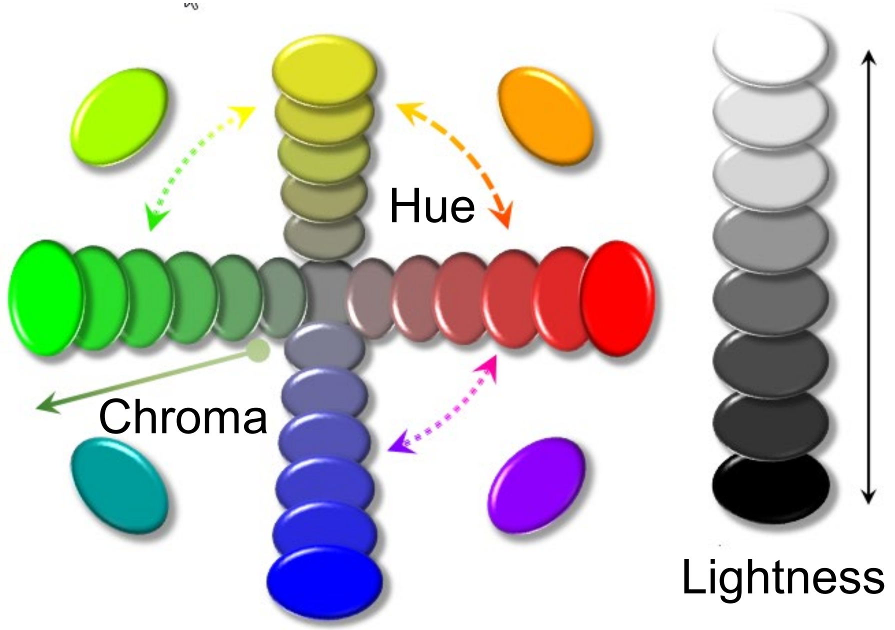
$X_n = 94.81$; $Y_n = 100.0$; $Z_n = 107.3$ For D65/10

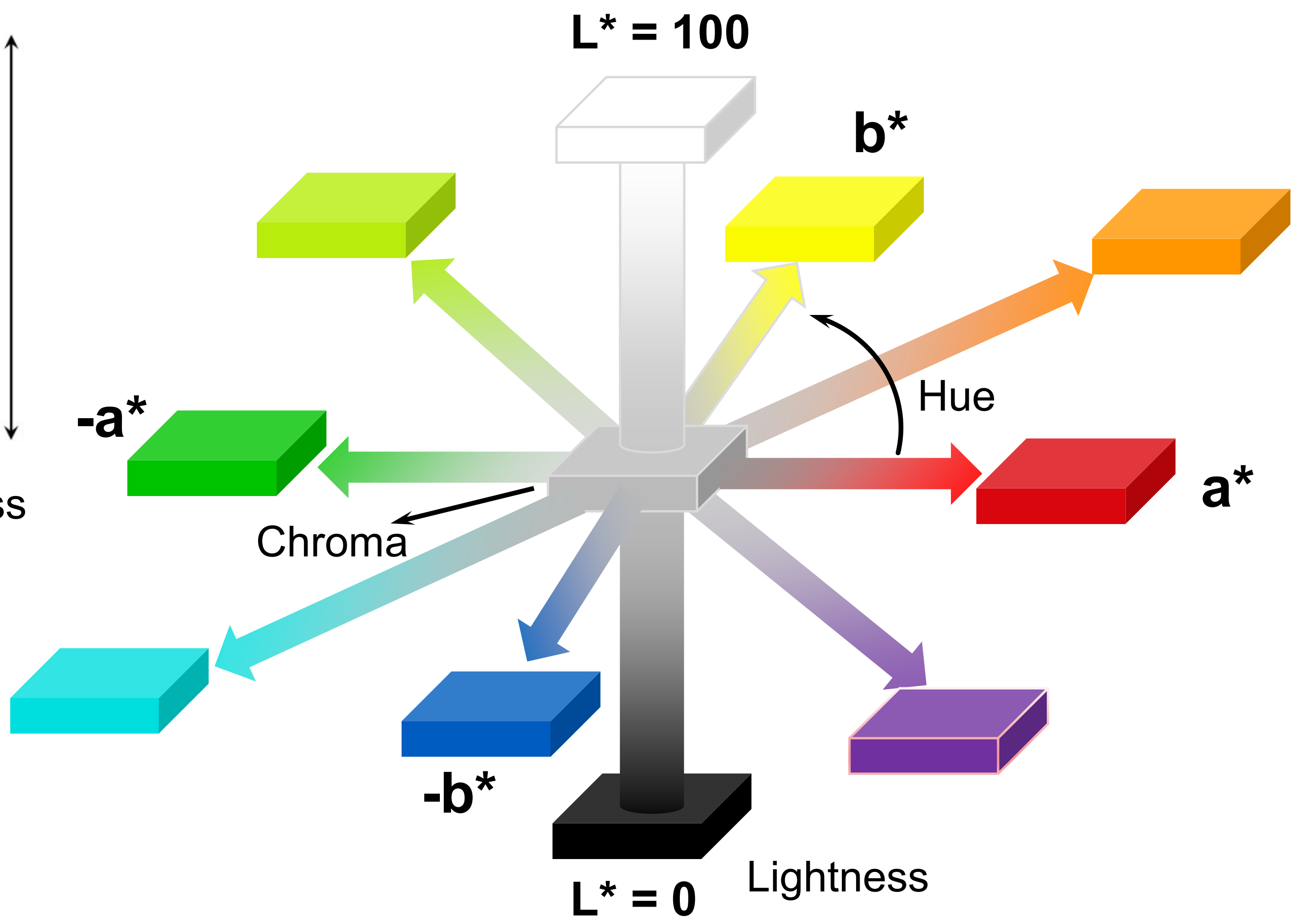


CIELAB

3 Dimensions of Color – Hue, Chroma, Lightness

datacolor Academy





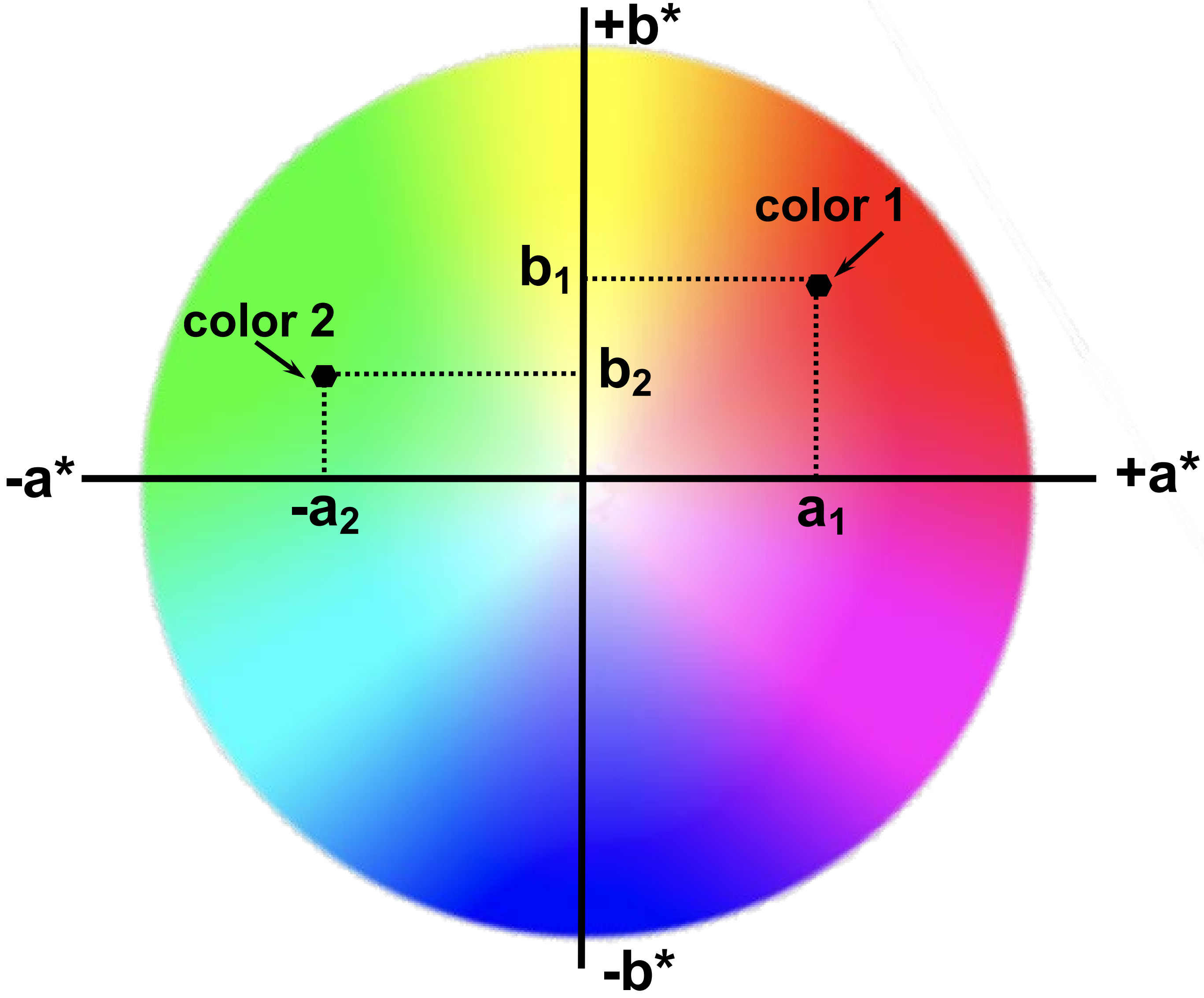
CIE L*a*b*

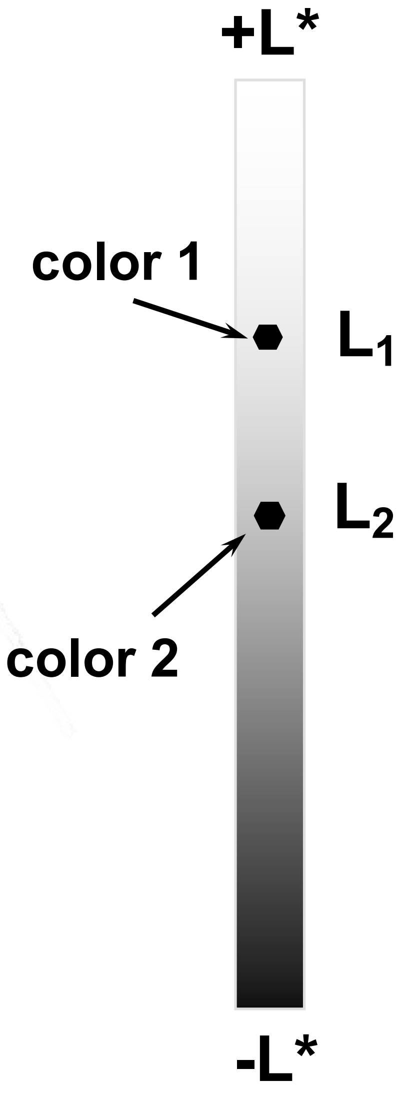
*L*a*b* Coordinates*

datacolor Academy

Color 1
L* = +65
a* = +10
b* = +10

Color 2
L* = +50
a* = -10
b* = +5





C* / h

Metric Chroma – Metric Hue Angle

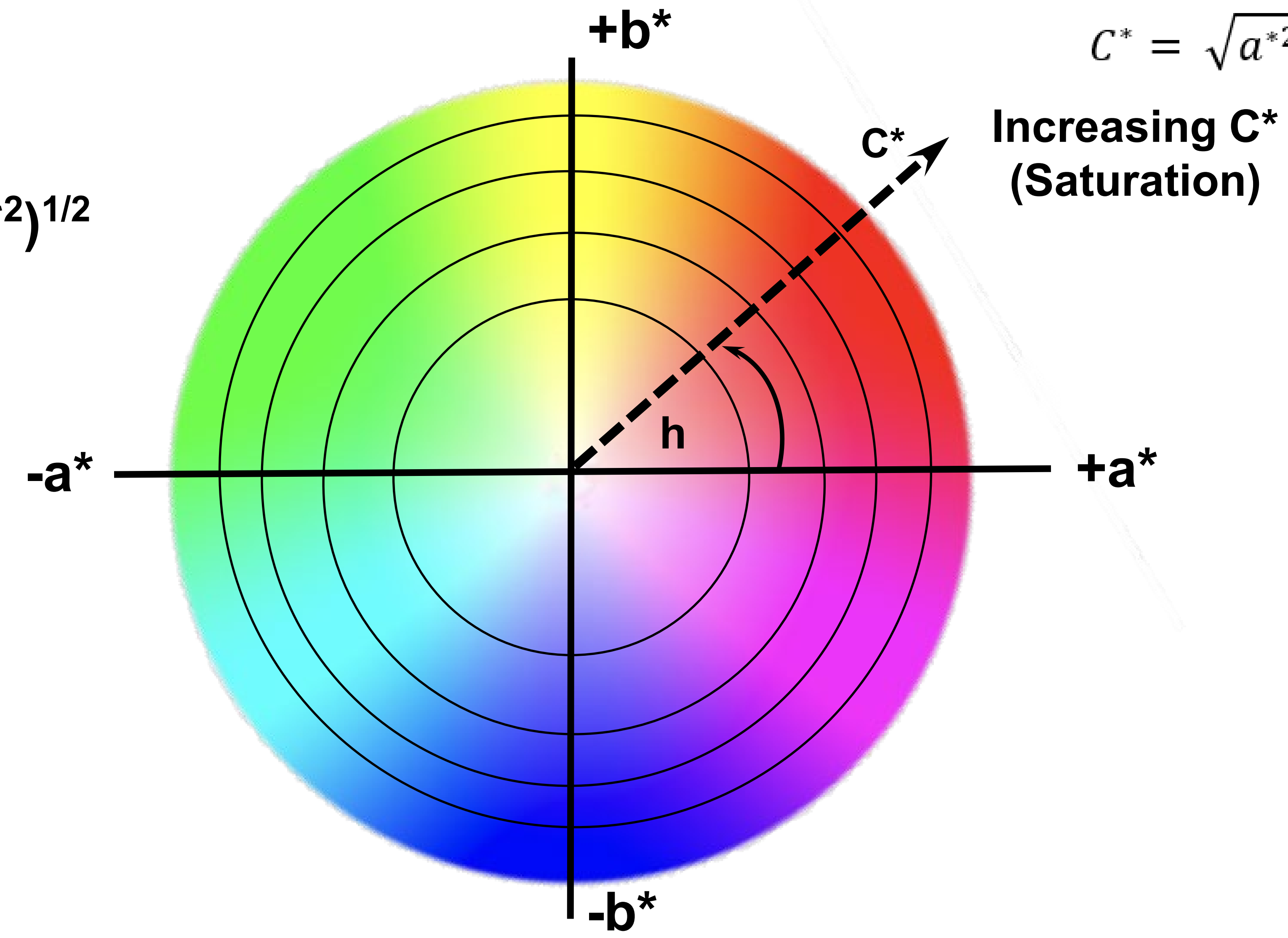
datacolor Academy

L*,C*,h

$C^* = (a^{*2} + b^{*2})^{1/2}$

$h = \tan^{-1}(b^*/a^*)$

$C^* = \sqrt{a^{*2} + b^{*2}}$



Color Difference

CIELAB Rectangular Coordinates – Da, Db*, DL**

datacolor Academy

$DE^* = (DL^{*2} + da^{*2} + db^{*2})^{1/2}$

$DL^* = L^*_{BAT} - L^*_{STD}$

(+ is lighter)
(- is darker)

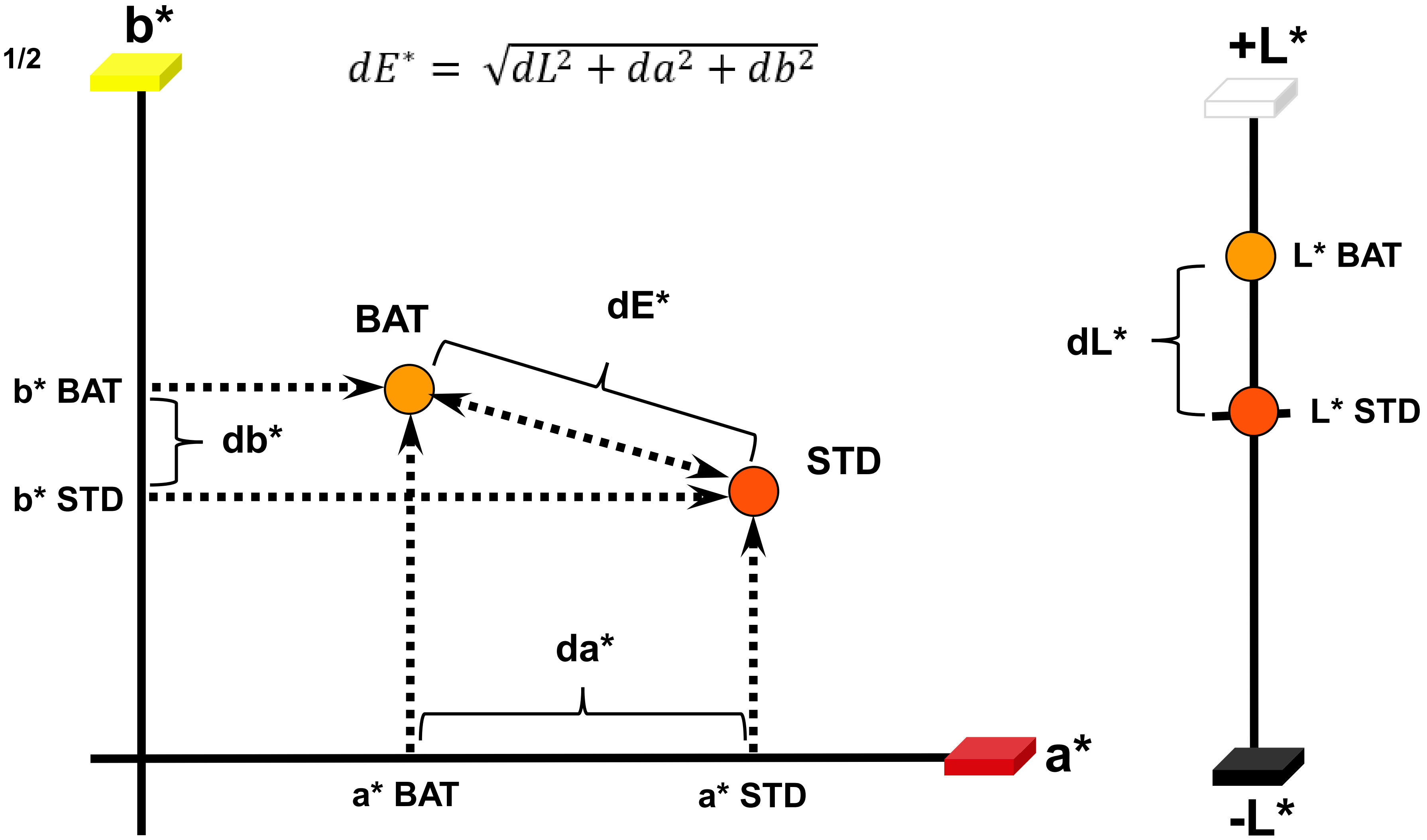
$da^* = a^*_{BAT} - a^*_{STD}$

(+ is redder, less green)
(- is greener, less red)

$db^* = b^*_{BAT} - b^*_{STD}$

(+ is yellower, less blue)
(- is bluer, less yellow)

$$dE^* = \sqrt{dL^2 + da^2 + db^2}$$



Color Difference

CIELAB Polar Coordinates – DL, DC*, DH*   Metric Hue Angle*

datacolor Academy

$C^* = (a^{*2} + b^{*2})^{1/2}$

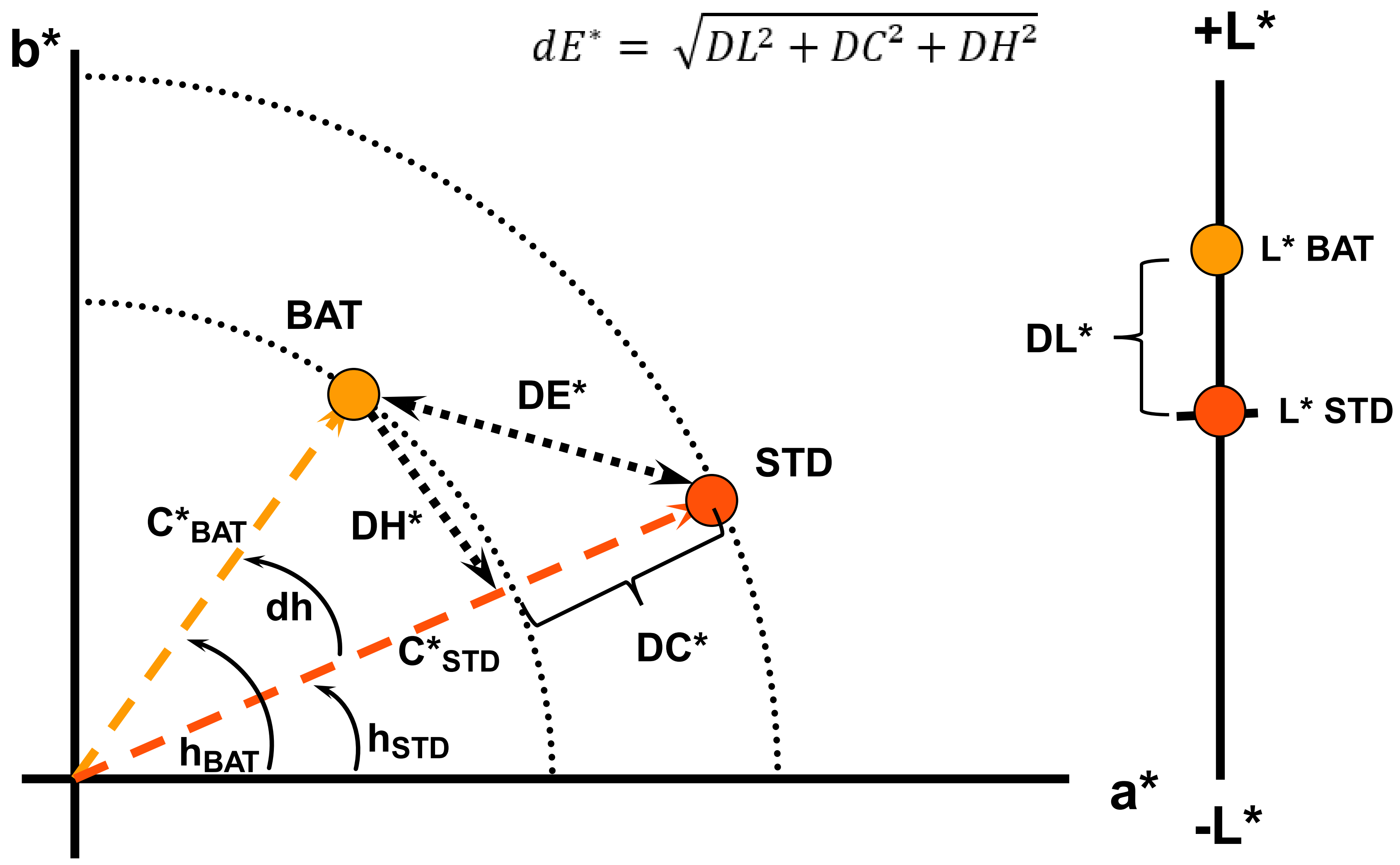
$h = \tan^{-1}(b^*/a^*)$

$DL^* = L^*_{BAT} - L^*_{STD}$
(+ is lighter)
(- is darker)

$DC^* = C^*_{BAT} - C^*_{STD}$
(+ is more chroma)
(- is less chroma)

$DH^* = 2(C^*_{STD} * C^*_{BAT})^{1/2} \sin(dh/2)$
(+ is counter-clockwise)

$DE^* = (DL^2 + DC^2 + DH^2)^{1/2}$



$$dE^* = \sqrt{DL^2 + DC^2 + DH^2}$$

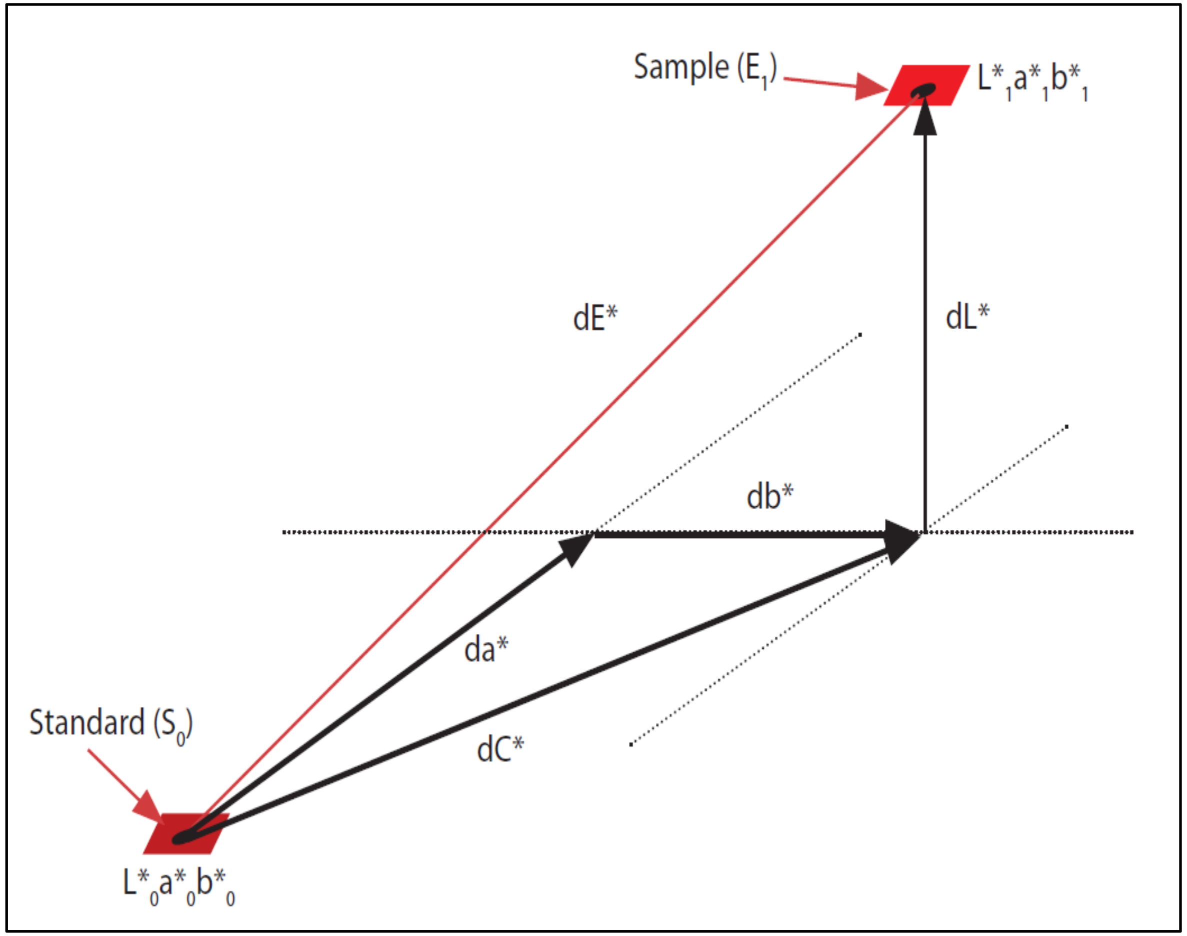
CIELAB

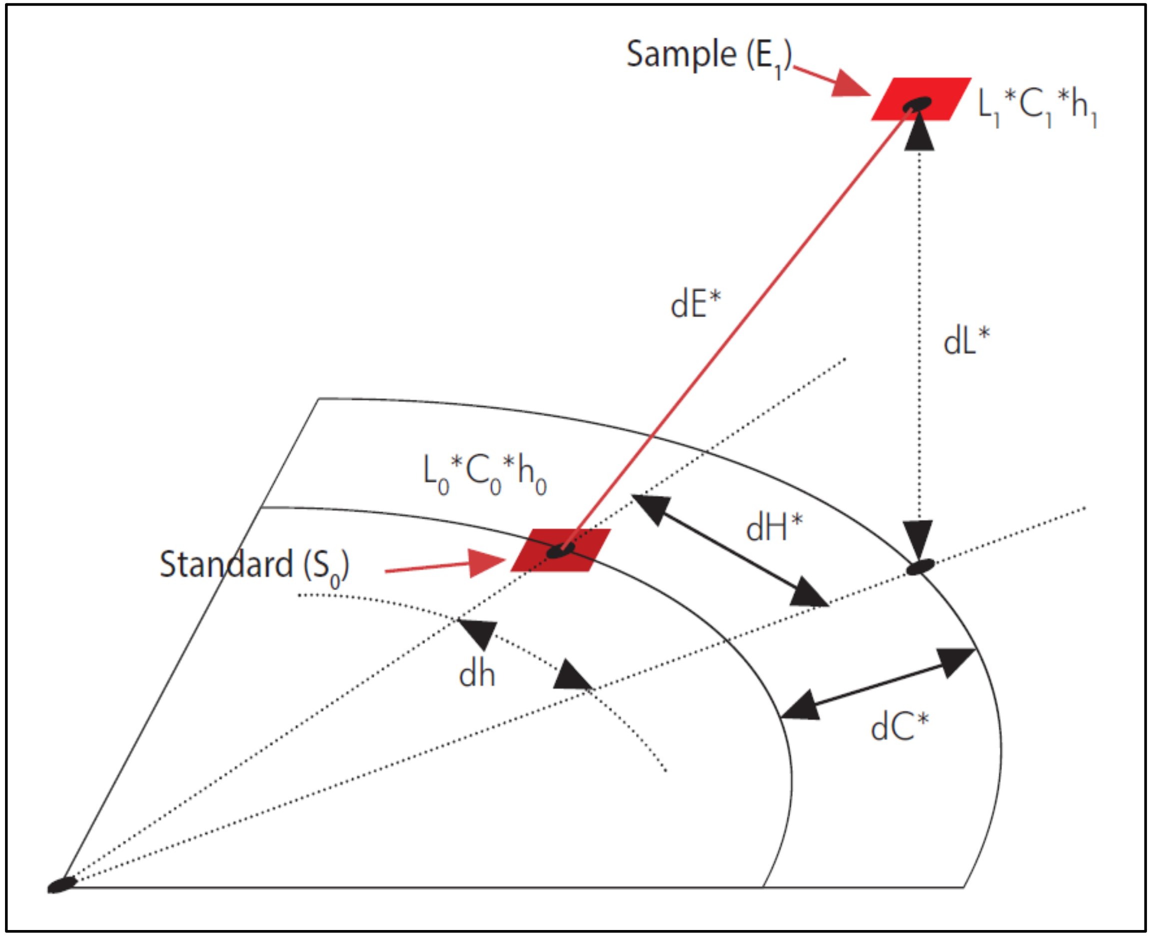
Rectangular and Polar Coordinates

datacolor Academy

$$dE^* = \sqrt{dL^2 + da^2 + db^2}$$

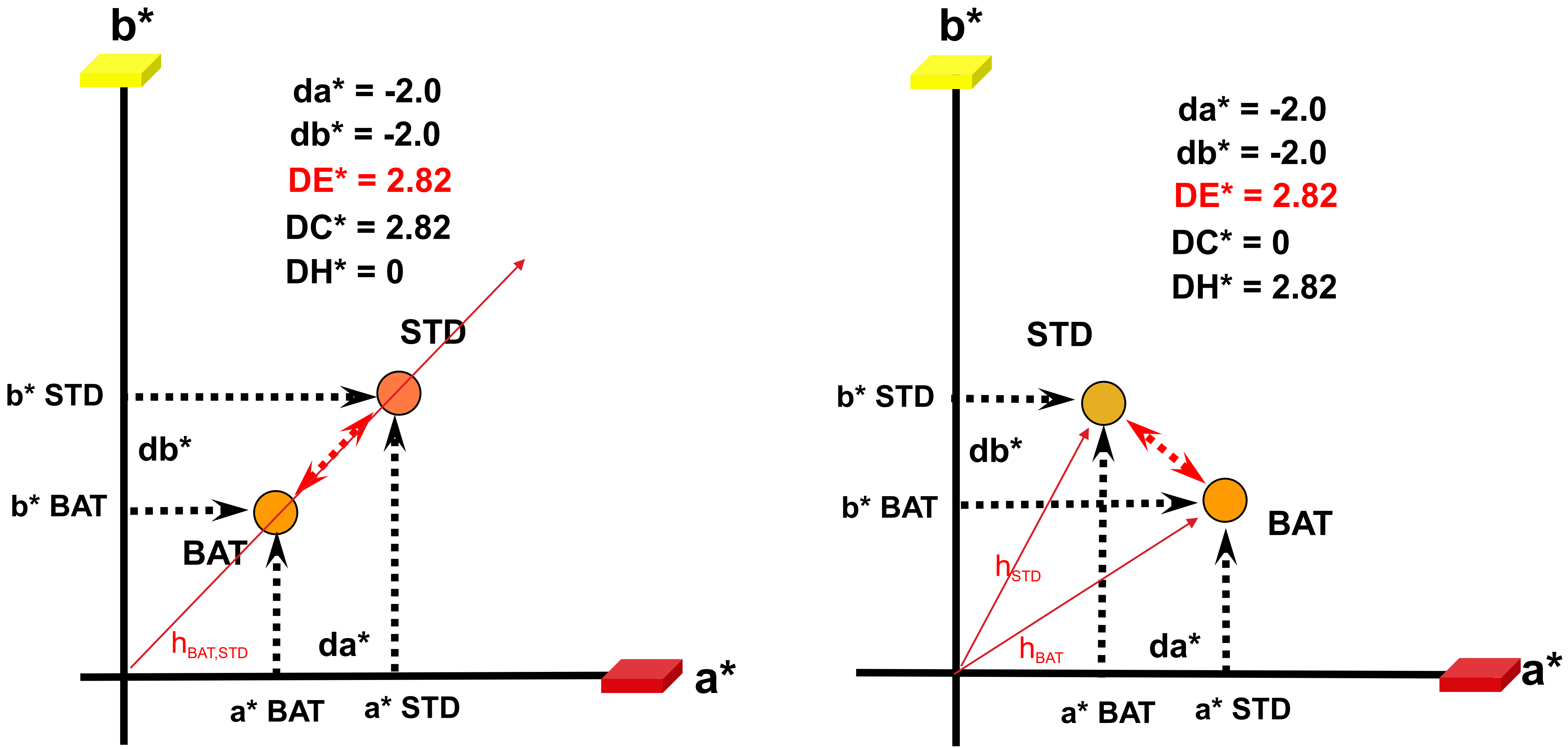
$$dE^* = \sqrt{DL^2 + DC^2 + DH^2}$$





Color Difference

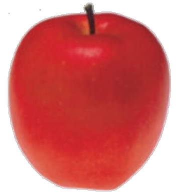
*CIELAB L*a*b* vs L*C*H**



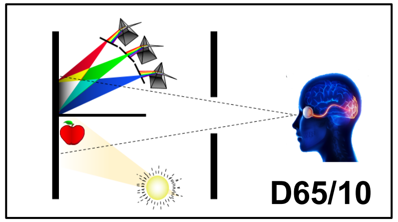
CIELAB Color Difference

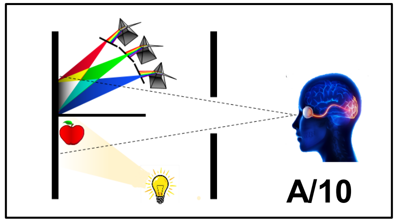
Red Apple 1 and Red Apple 2

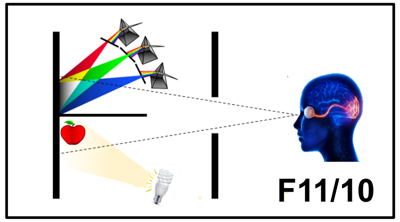
datacolor Academy

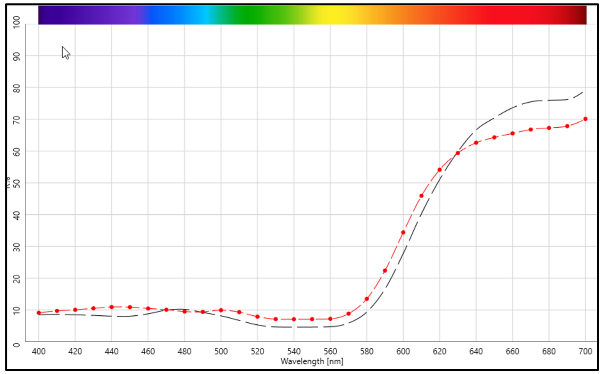


Red Apple 1



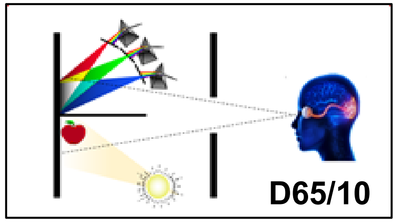


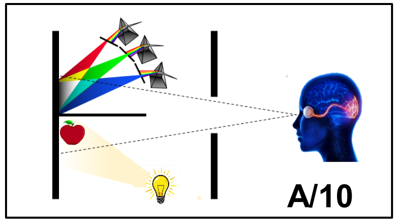


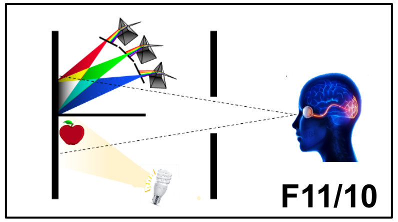


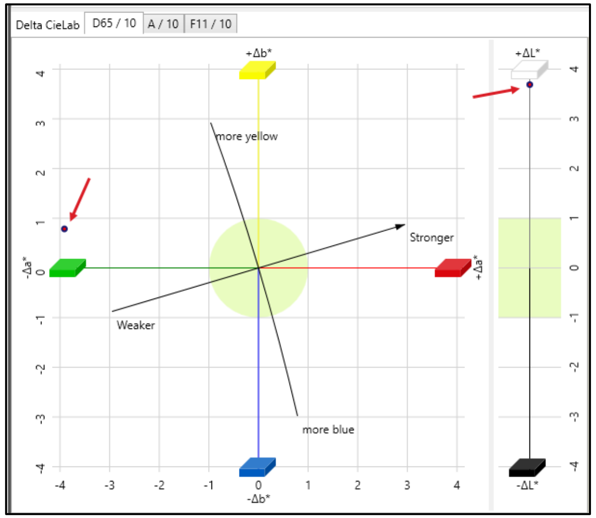
Current Illumi	Std. Name	Std. CIE X	Std. CIE Y	Std. CIE Z	Std. CIE L	Std. CIE a	Std. CIE b	Std. CIE C	Std. CIE h
D65 10 Deg	Red Apple 1	21.65	13.60	9.29	43.65	48.50	14.38	50.58	16.51
A 10 Deg		34.21	18.83	3.06	50.49	51.01	26.02	57.26	27.03
F11 10 Deg		26.83	15.91	5.58	46.86	47.48	20.42	51.68	23.27

Red Apple 2





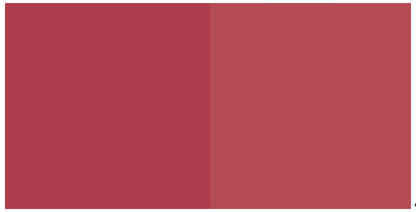




Current Illumi	Batch Name	Batch CIE X	Batch CIE Y	Batch CIE Z	Batch CIE L	Batch CIE a	Batch CIE b	Batch CIE C	Batch CIE h
D65 10 Deg	Red Apple 2	24.30	16.28	11.16	47.34	44.58	15.16	47.09	18.78
A 10 Deg		37.04	21.62	3.62	53.62	46.57	26.30	53.49	29.45
F11 10 Deg		30.77	19.11	6.90	50.82	45.29	20.79	49.84	24.66

CIELAB Color Difference – DL*, Da*, Db*, DC*, DH*, DE*

Current Illumi	Batch Name	CIE DL	CIE Da	CIE Db	CIE DC	CIE DH	CIE DE
D65 10 Deg	Red Apple 2	3.69	-3.92	0.78	-3.50	1.93	5.44
A 10 Deg		3.13	-4.44	0.28	-3.78	2.34	5.44
F11 10 Deg		3.96	-2.19	0.37	-1.85	1.23	4.54

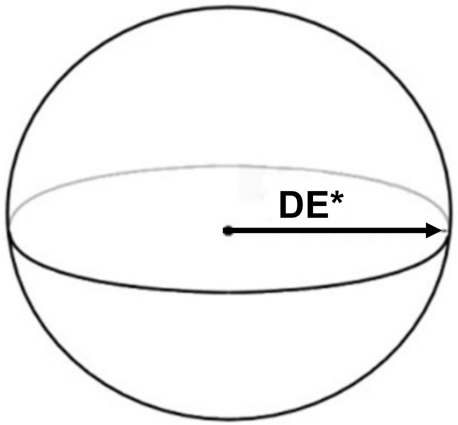


CMC Color Difference Equation

Ellipsoidal Tolerancing

datacolor Academy

DE*



$$\Delta E^*_{CMC(l:c)} = \left[\left(\frac{\Delta L^*}{lS_L}\right)^2 + \left(\frac{\Delta C^*_{ab}}{cS_C}\right)^2 + \left(\frac{\Delta H^*_{ab}}{S_H}\right)^2\right]^{1/2}$$

S_L = Lightness Tolerance

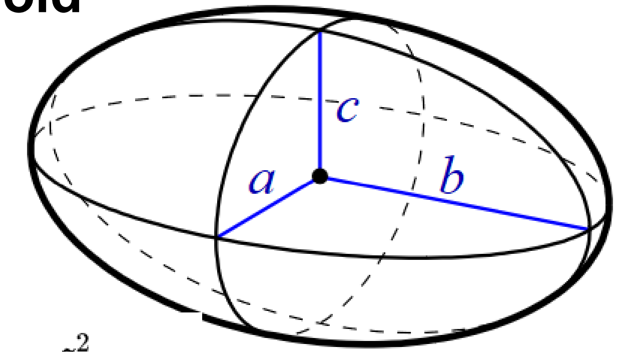
S_C = Chroma Tolerance

S_H = Hue Tolerance

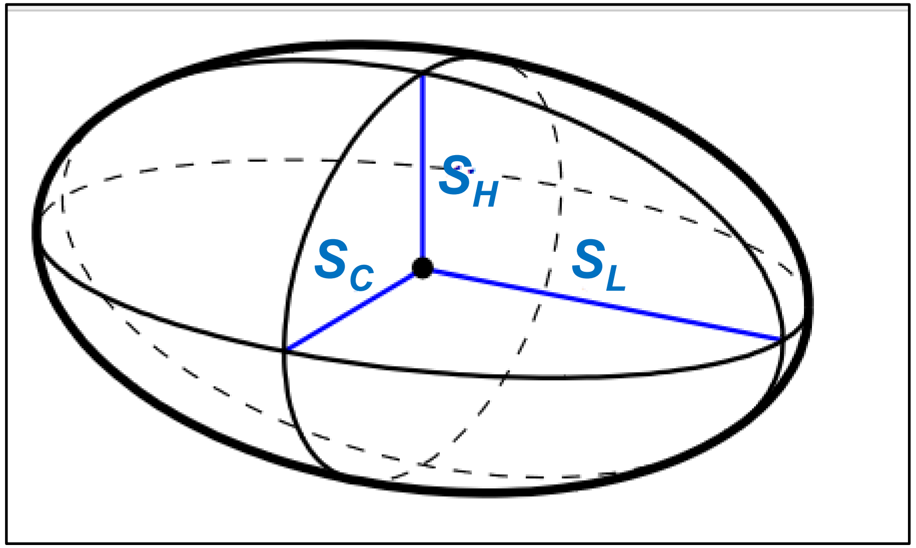
l = Lightness Adjustment Factor

c = Chroma Adjustment Factor

Ellipsoid



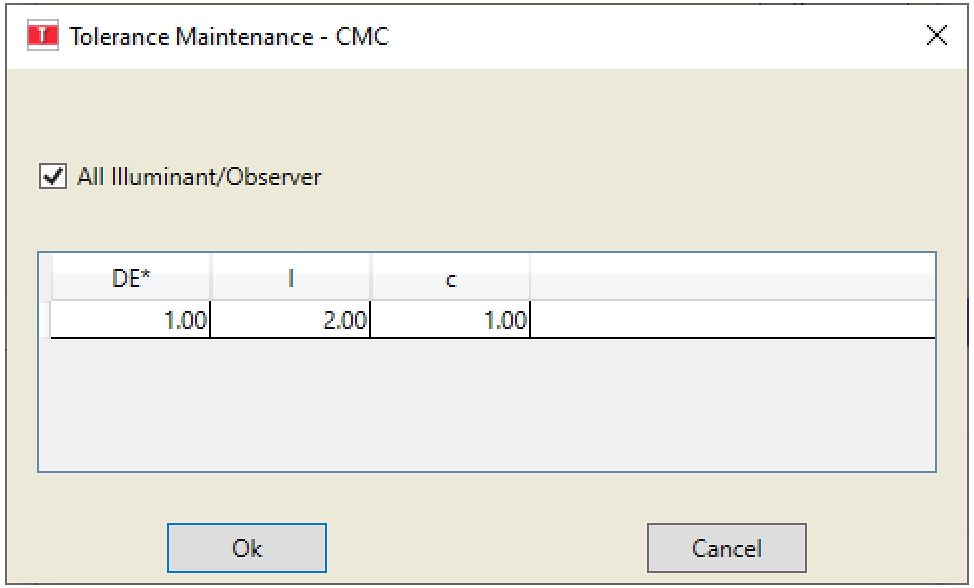
$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1$$



CMC Color Difference Equation

Meaning of the Value of the CMC DE

datacolor Academy



$$\Delta E^*_{CMC(l:c)} = \left[\left(\frac{\Delta L^*}{lS_L}\right)^2 + \left(\frac{\Delta C^*_{ab}}{cS_C}\right)^2 + \left(\frac{\Delta H^*_{ab}}{S_H}\right)^2\right]^{1/2}$$

l = Lightness Factor

Allows adjustment of DL* Semi-axis

c = Chroma Factor

Allows adjustment of DC* Semi-axis

$DE^*_{CMC} = 1.0$

Batch is on surface of ellipsoid.

$DE^*_{CMC} < 1.0$

Batch is inside ellipsoid (Pass)

$DE^*_{CMC} > 1.0$

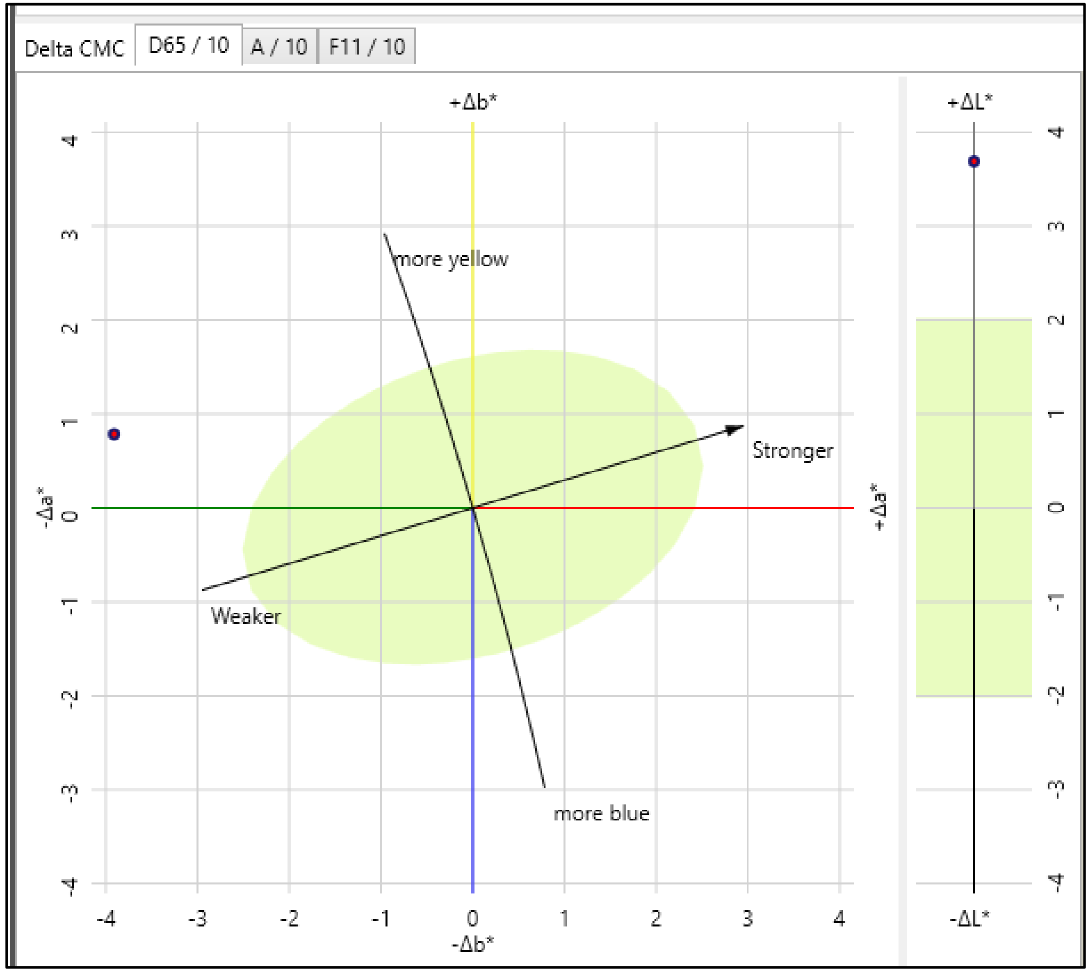
Batch is outside ellipsoid (Fail)

CMC Color Difference Equation

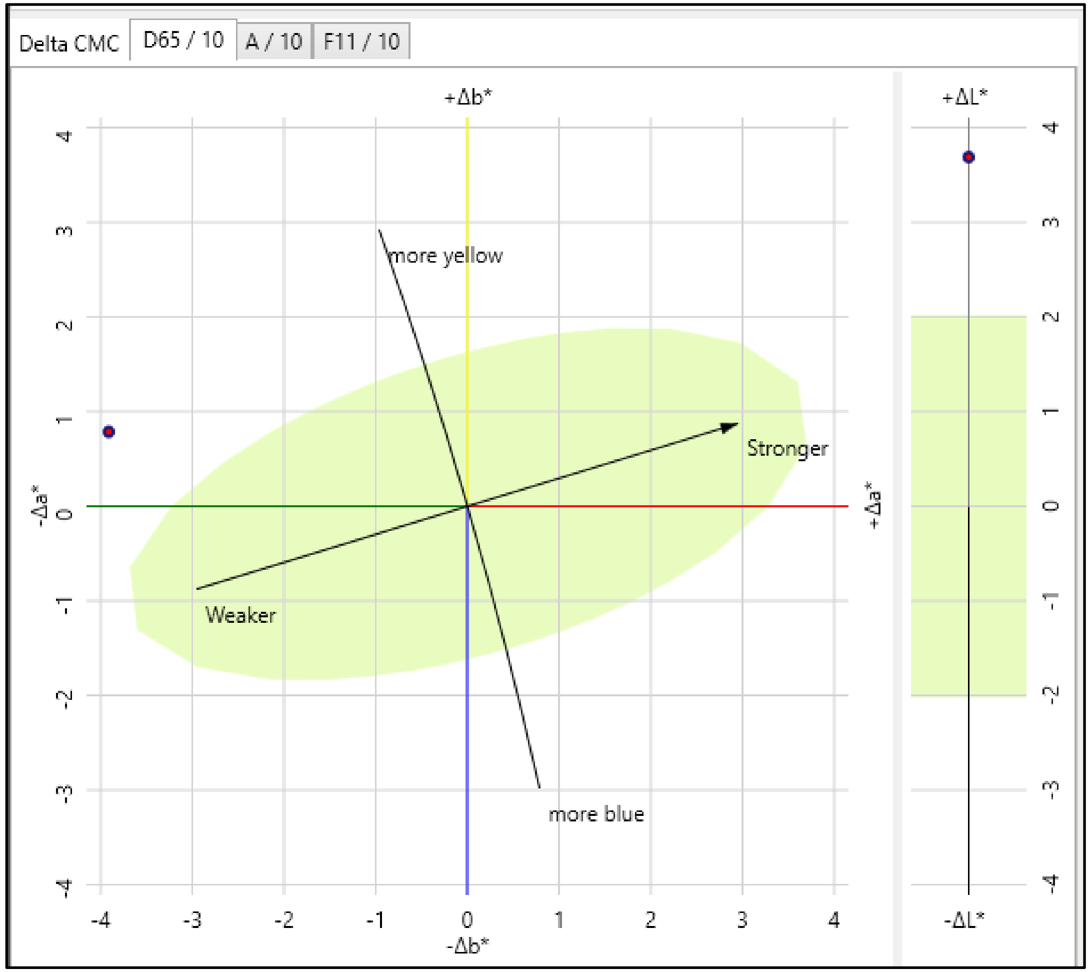
Changing the Value of the CMC Adjustment Factor

datacolor Academy

l = 2 c = 1



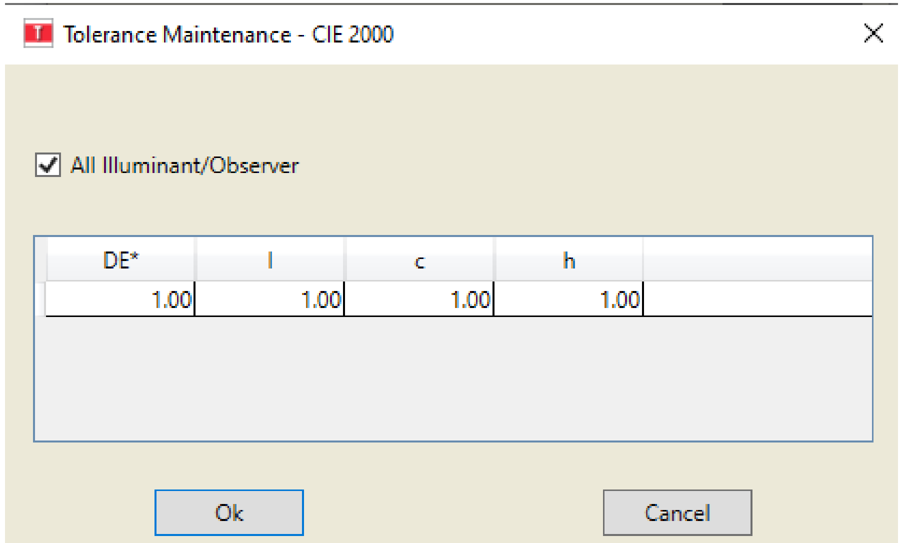
l = 2 c = 1.5



CIE 2000 Color Difference Equation

Meaning of the Value of the CIE 2000 DE

datacolor Academy



$$\Delta E^*_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C} \frac{\Delta H'}{k_H S_H}}$$

Includes lightness, chroma and hue weighting factors
Improved gray colors
Improved performance for blue colors using rotational factor

K_L = Lightness Factor
Allows adjustment of DL* Semi-axis

K_C = Chroma Factor
Allows adjustment of DC* Semi-axis

K_H = Hue Factor
Allows adjustment of DH* Semi-axis

S_L = Lightness Tolerance

S_C = Chroma Tolerance

S_H = Hue Tolerance

$DE^*_{00} = 1.0$
Batch is on surface of ellipsoid.

$DE^*_{00} < 1.0$
Batch is inside ellipsoid (Pass)

$DE^*_{00} > 1.0$
Batch is outside ellipsoid (Fail)

Webinar – Final Comments

Questions

Next session:

datacolor Academy

We will talk about color tolerances

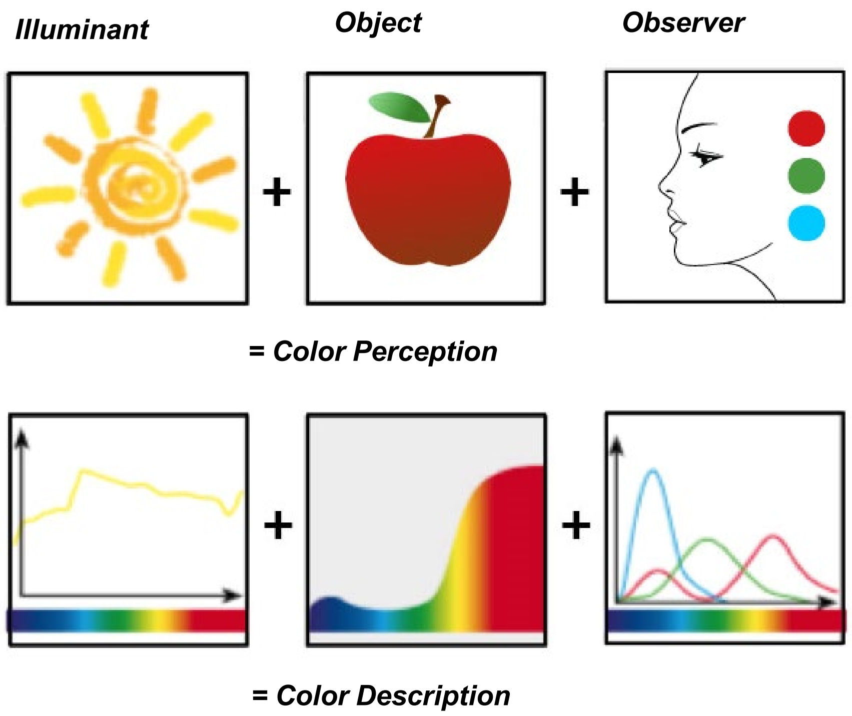
Color Tolerances

DE

Rectangular

Ellipsoidal

AI Tolerancing



datacolor Academy

Want to learn more?

Sign up at Datacolor Academy for classroom style lectures and demonstrations covering useful color topics in select venues around the globe

Some useful reading material:

Do You Know How Humans See Color?

Follow Datacolor Blog for more useful information

datacolor Academy

Thank you and follow us:

www.facebook.com/DatacolorCorporate

www.linkedin.com/company/datacolor

www.youtube.com/user/DatacolorIndustrial