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Color Theory – Part 2

Color Communication

Color Theory – Part 2

Color Communication

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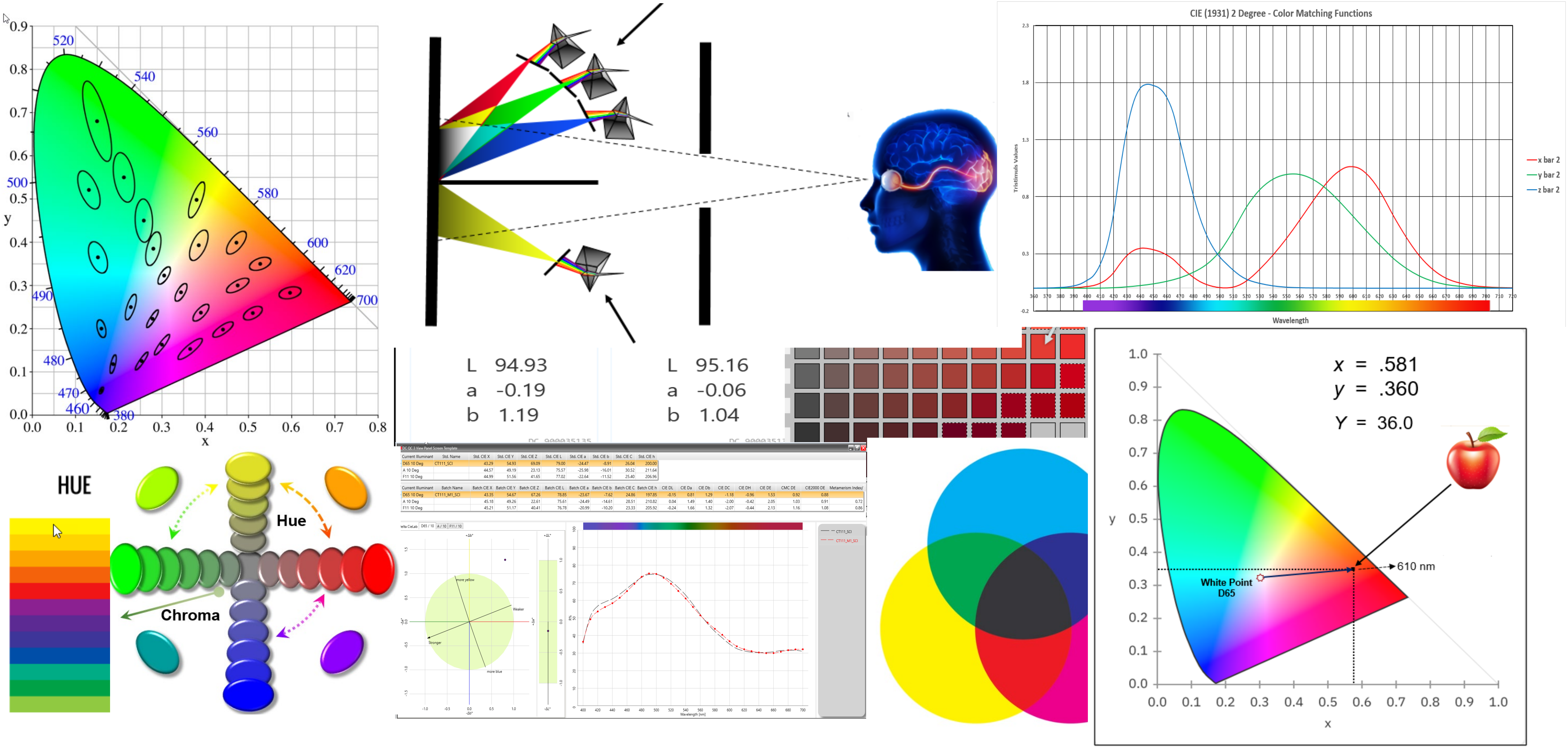

Review

Color is a **perception** by an ***observer*** of ***light*** which has been modified by an ***object***.

Light Source

Object

Observer

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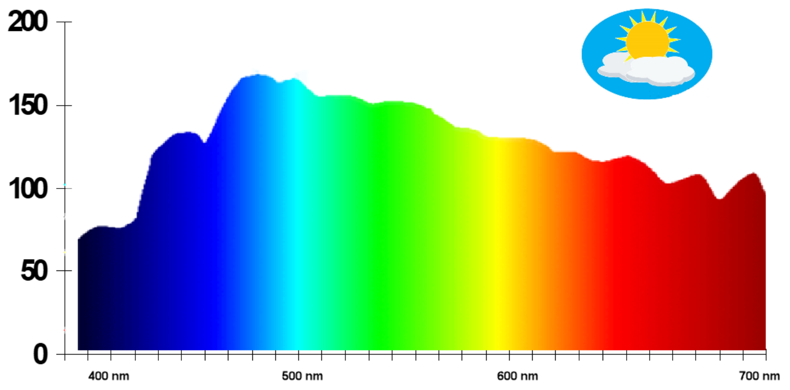
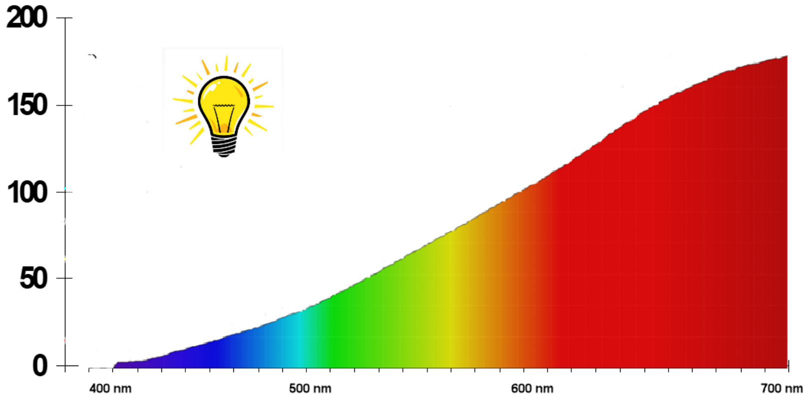
Review - Light Sources

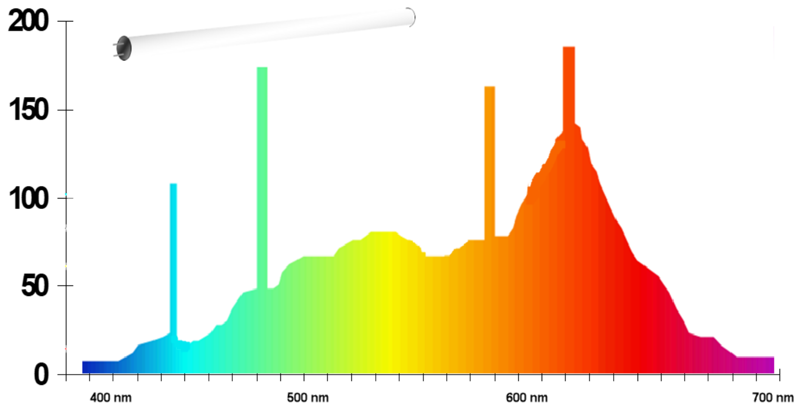
Daylight



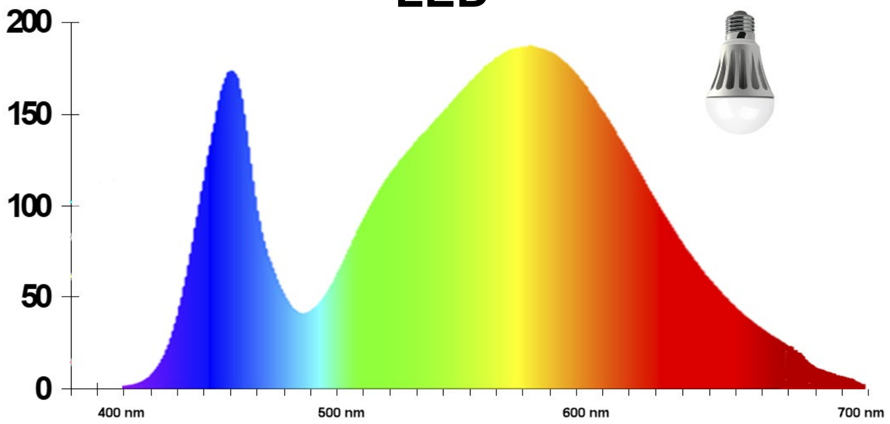
Incandescent



Fluorescent



LED



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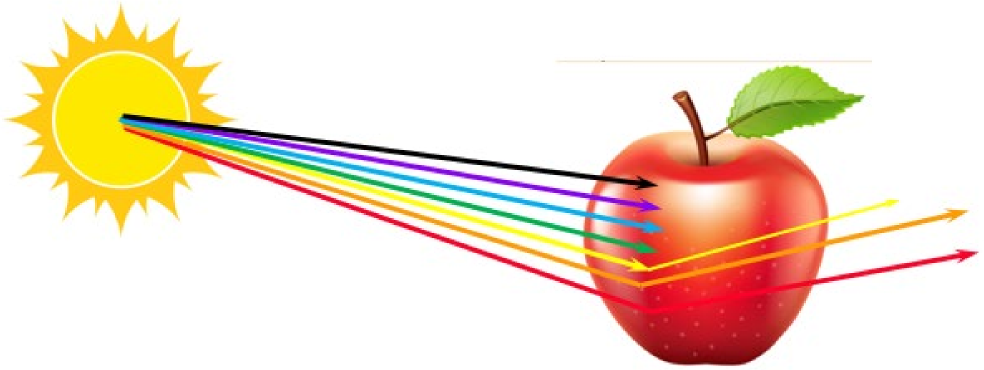
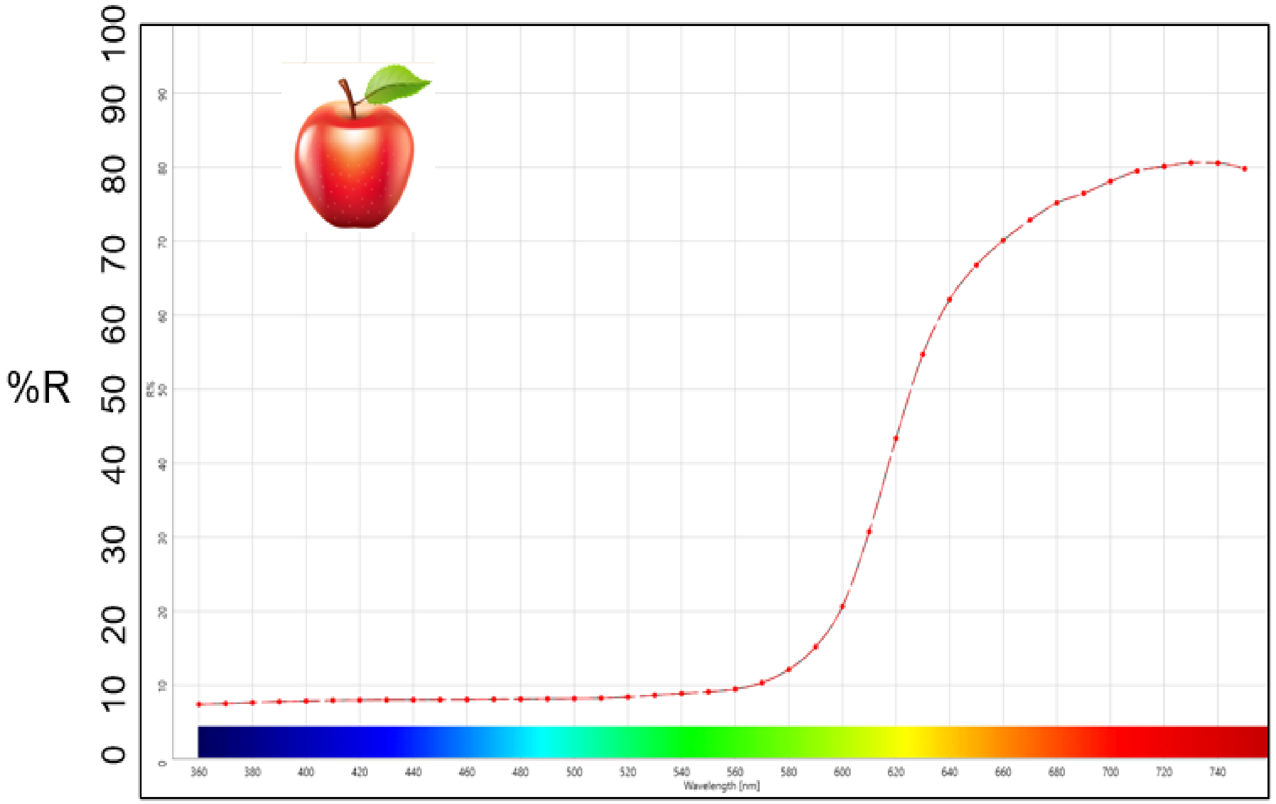
Review - The Object



The spectral reflectance curve (%R) curve shows the amount of light reflected at each wavelength.



Objects modify the incident light by absorbing some wavelengths and reflecting others.

Review - The Observer

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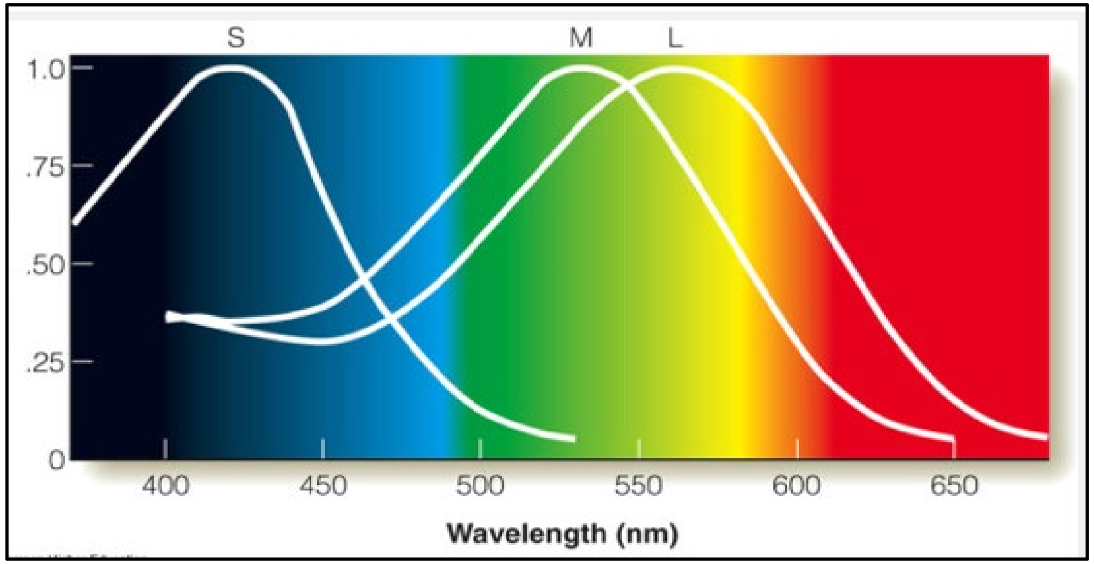
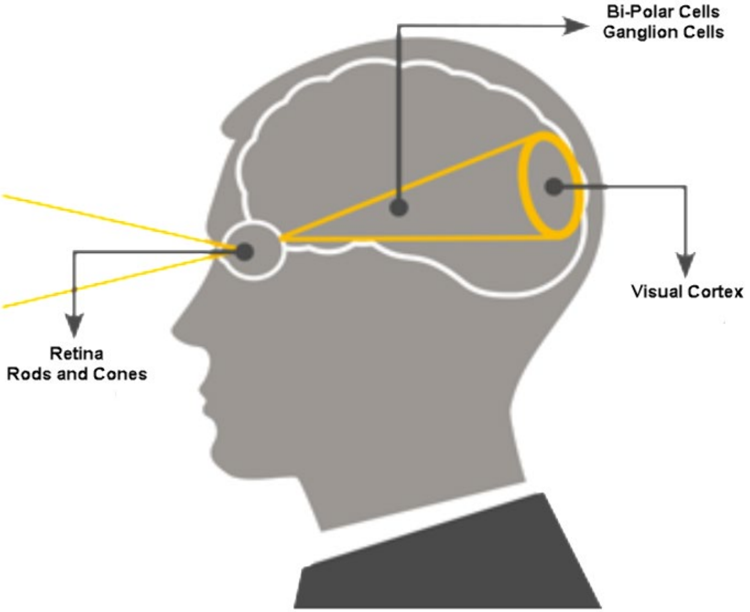
We discussed the human observer and how the eye and brain work together to produce the perception of color. The retina in the eye contains rods and cones which detect the incoming light. The cones are responsible for color vision while the rods are responsible for dark adapted vision.

The Trichromatic Theory and the Opponent Theory state that vision involves a progression of neural processes from rods and cones to the bipolar cells to the ganglion cells and then to the visual cortex and the rest of the brain.





Color Communication

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Color Perception and the Need for a Colorimetric Description

In our previous webinar, we were able to define on a quantitative basis how light sources and objects contribute to the perception of color. The human observer, however, was not shown as a measurable entity.

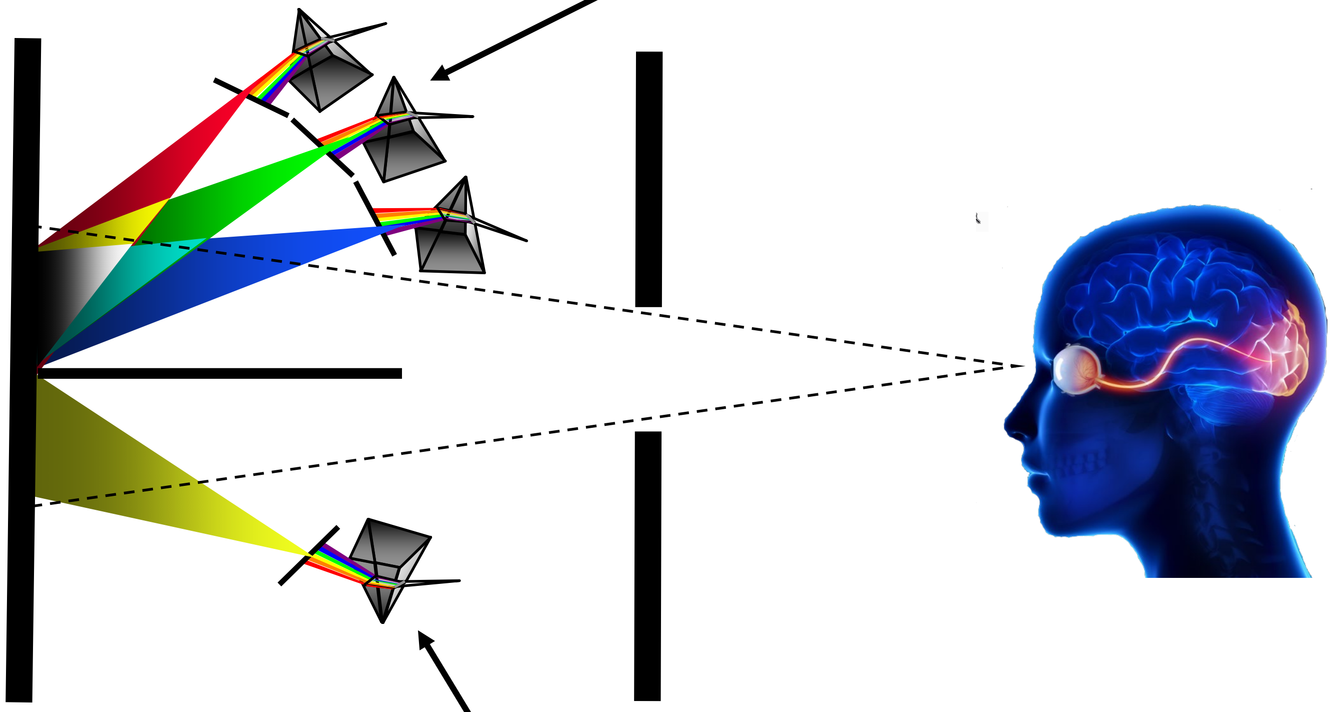
In order to define a colorimetric description, the color sensitivity of the human observer to different wavelengths of light would need to be standardized and made available in a numerical form.

The CIE Standard Observer is a table of numbers designed to represent a normal observer, but its responses do not refer to any specific observer. The Standard Observer is a numerical representation of what the “average person” sees.

The Standard Observer will provide a method to compare instrumental color measurements to human visual assessments. Let’s look at the experimental setup that was used to create the Standard Observer.

The Standard Observer

Experiment Setup



The Standard Observer

Adjusting to match the yellow primary lamp

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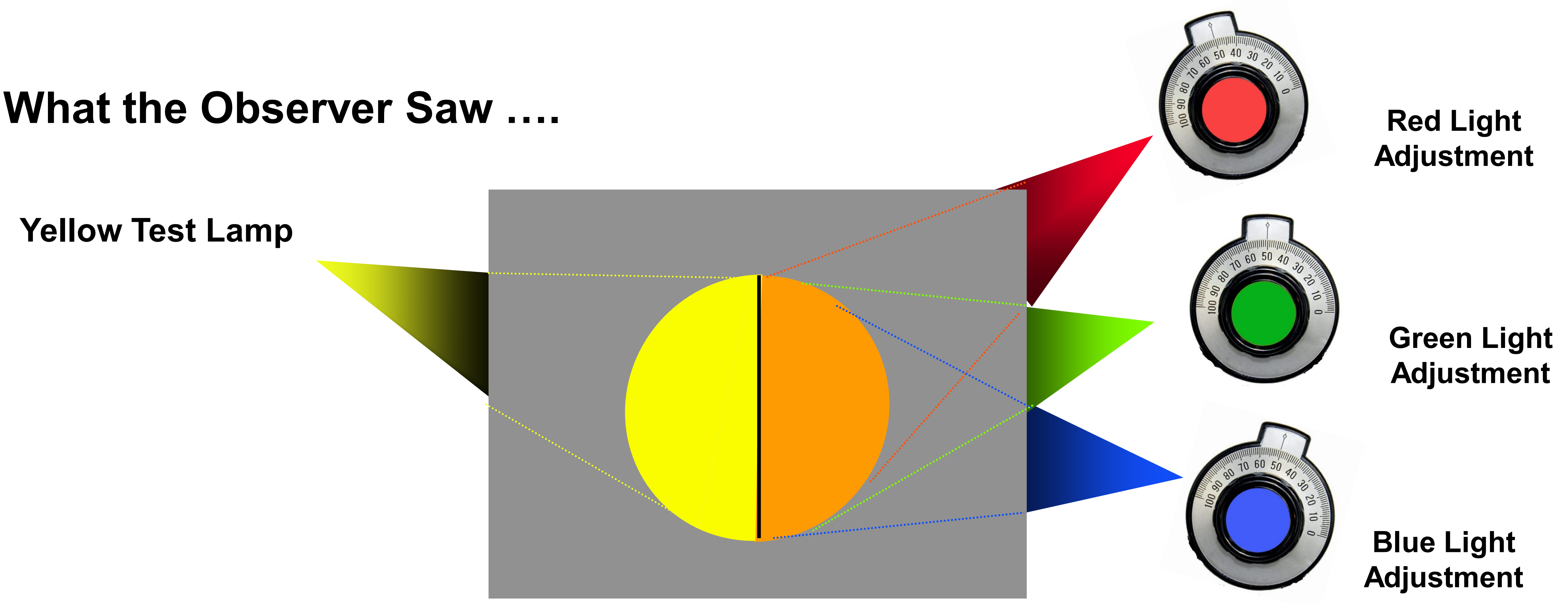
What the Observer Saw ….



The observer adjusted the red, green and blue lights until a color match was achieved.

The Standard Observer

Successfully matched the yellow primary lamp

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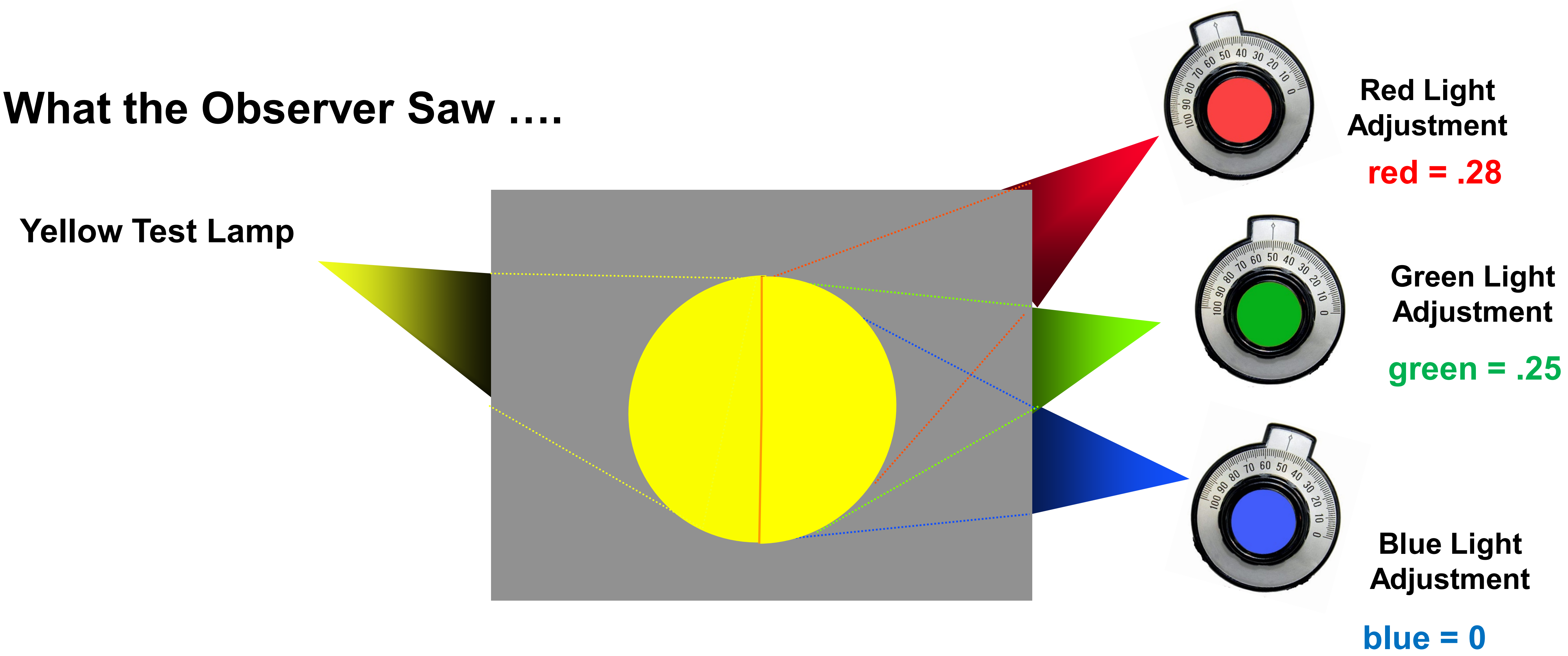
What the Observer Saw ….



Color was matched with .28 red, .25 green and 0 blue.

The Standard Observer

Adjusting to match the violet primary lamp

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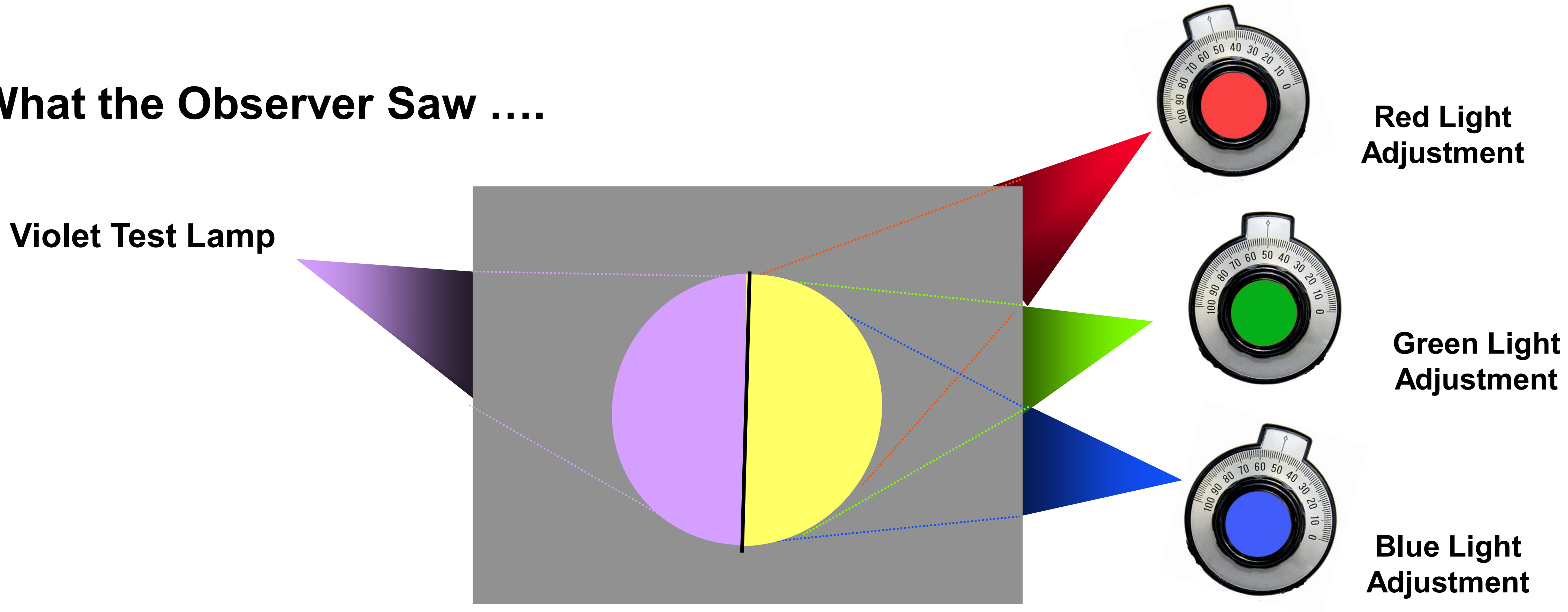
What the Observer Saw ....



The observer adjusted the red, green and blue lights until a color match was achieved.

The Standard Observer

Successfully matched the violet primary lamp

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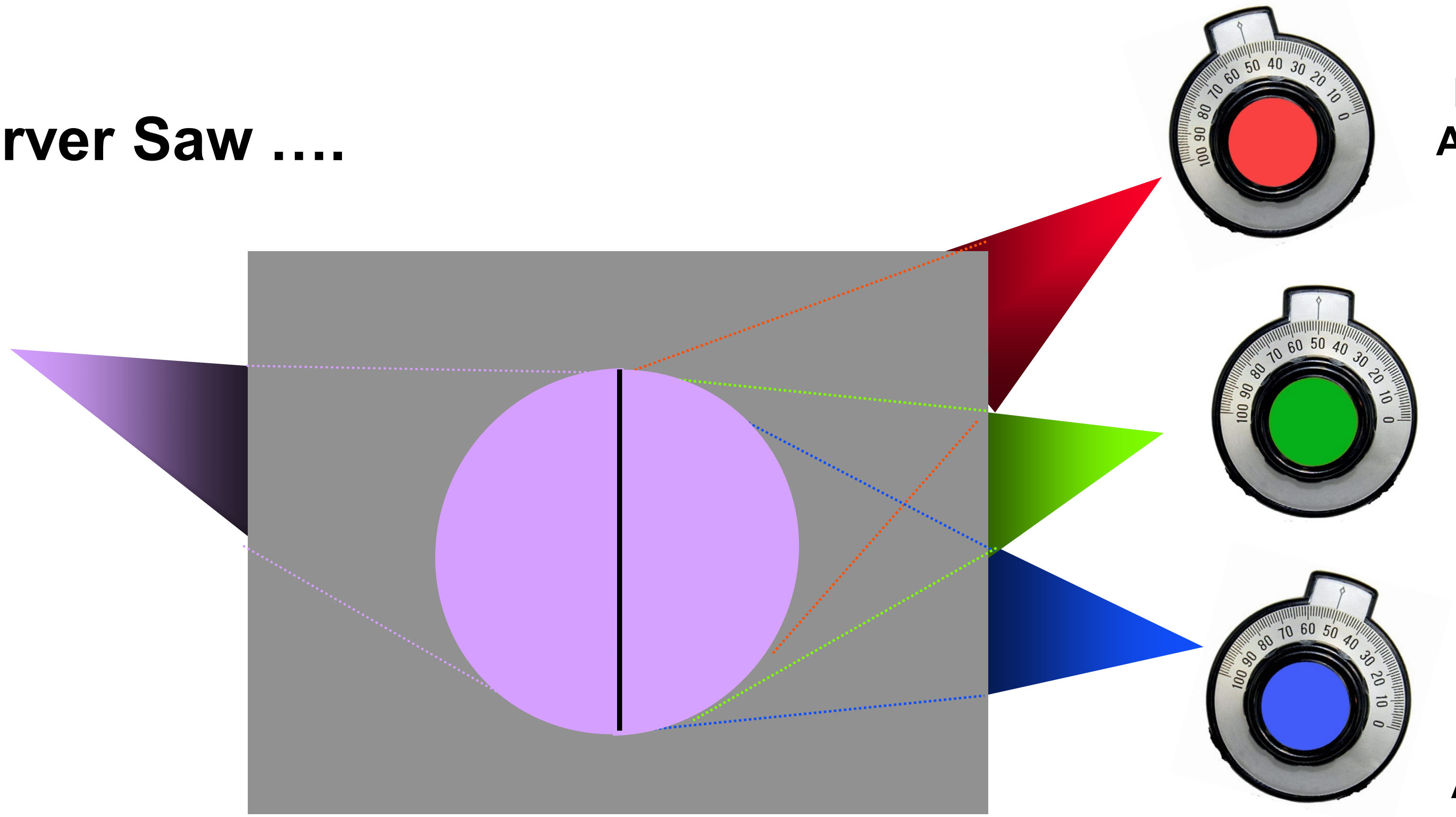
What the Observer Saw ….

Violet Test Lamp



Red Light Adjustment

red = .21

Green Light Adjustment

green = .08

Blue Light Adjustment

blue = .24

Color was matched with .21 red, .08 green and .24 blue.

The Standard Observer

Results of the color matching experiments of Wright and Guild

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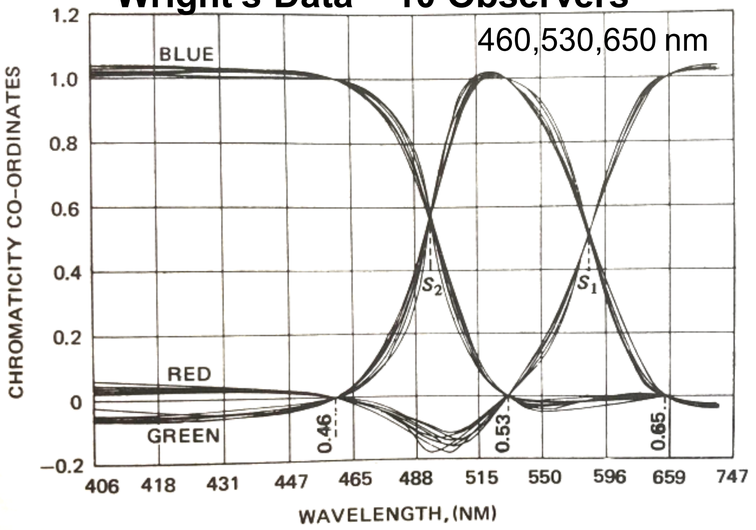
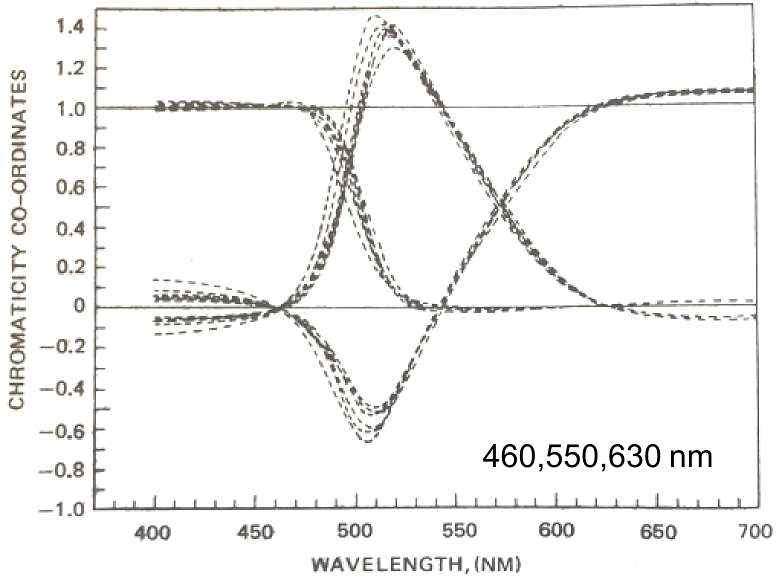
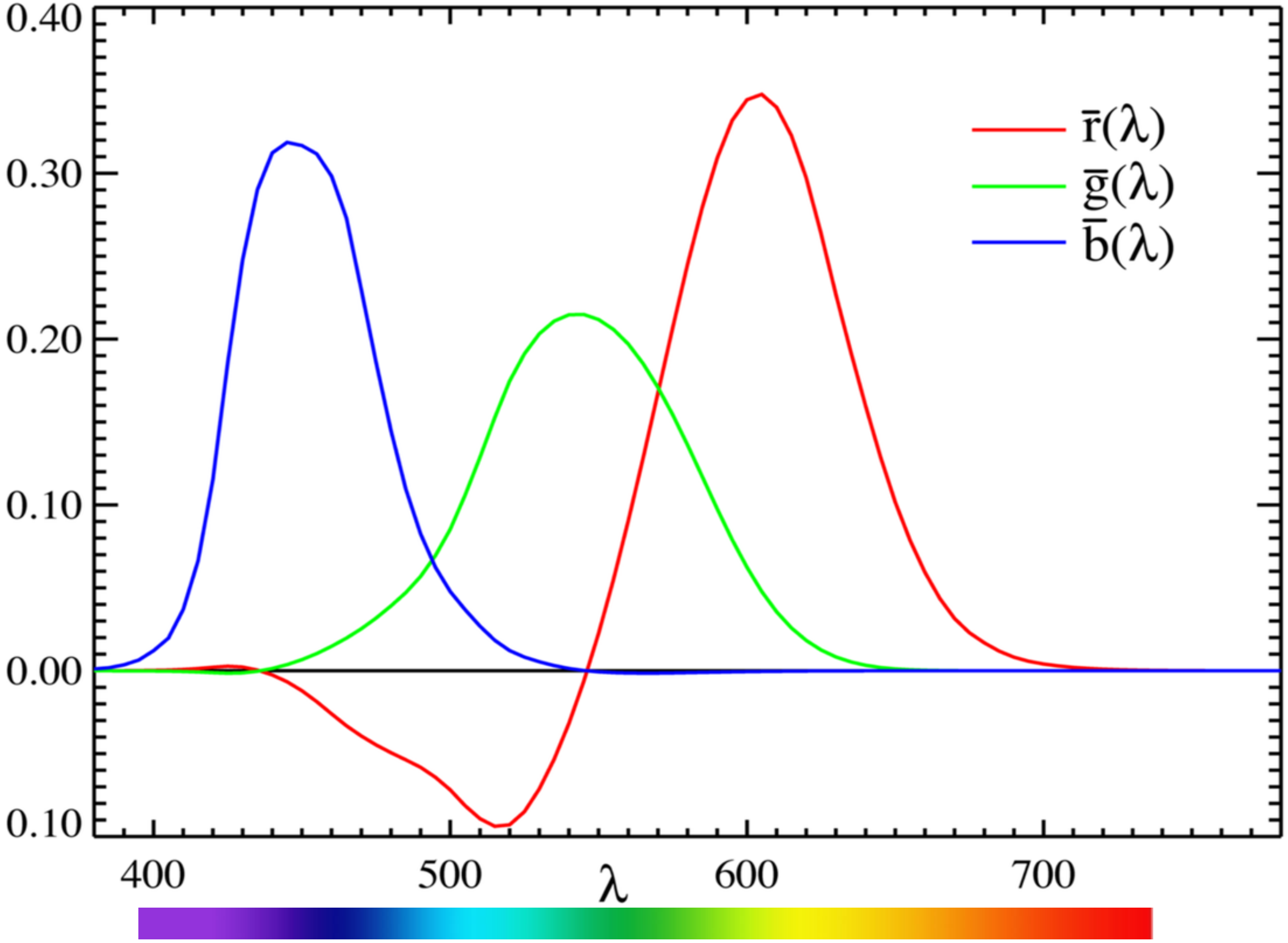
Wright's Data – 10 Observers



Guild's Data – 7 Observers





The Standard Observer

Reason for negative numbers

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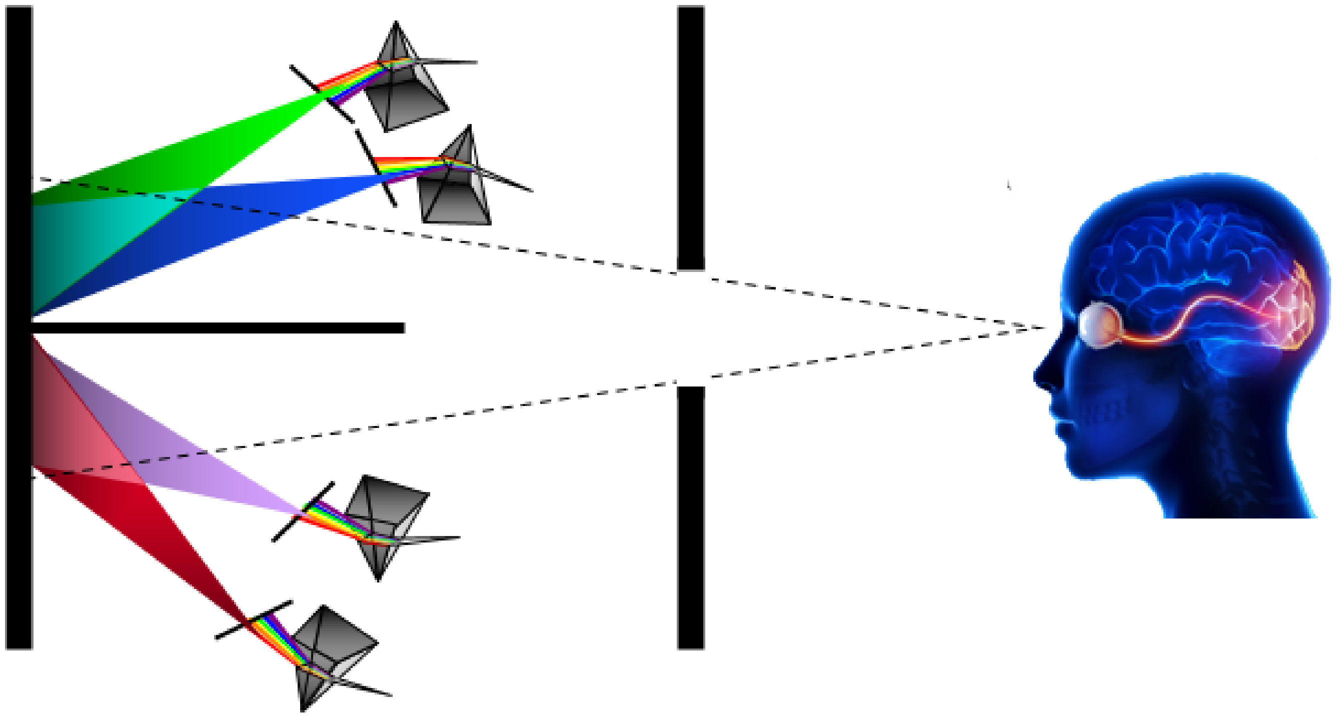
Since it is impossible to match all spectrum colors using positive amounts of any set of three real lamps, in some cases one of the primary lamps was moved to the test lamp side.

This created “negative numbers” in the data.



1931 2° – Standard Observer

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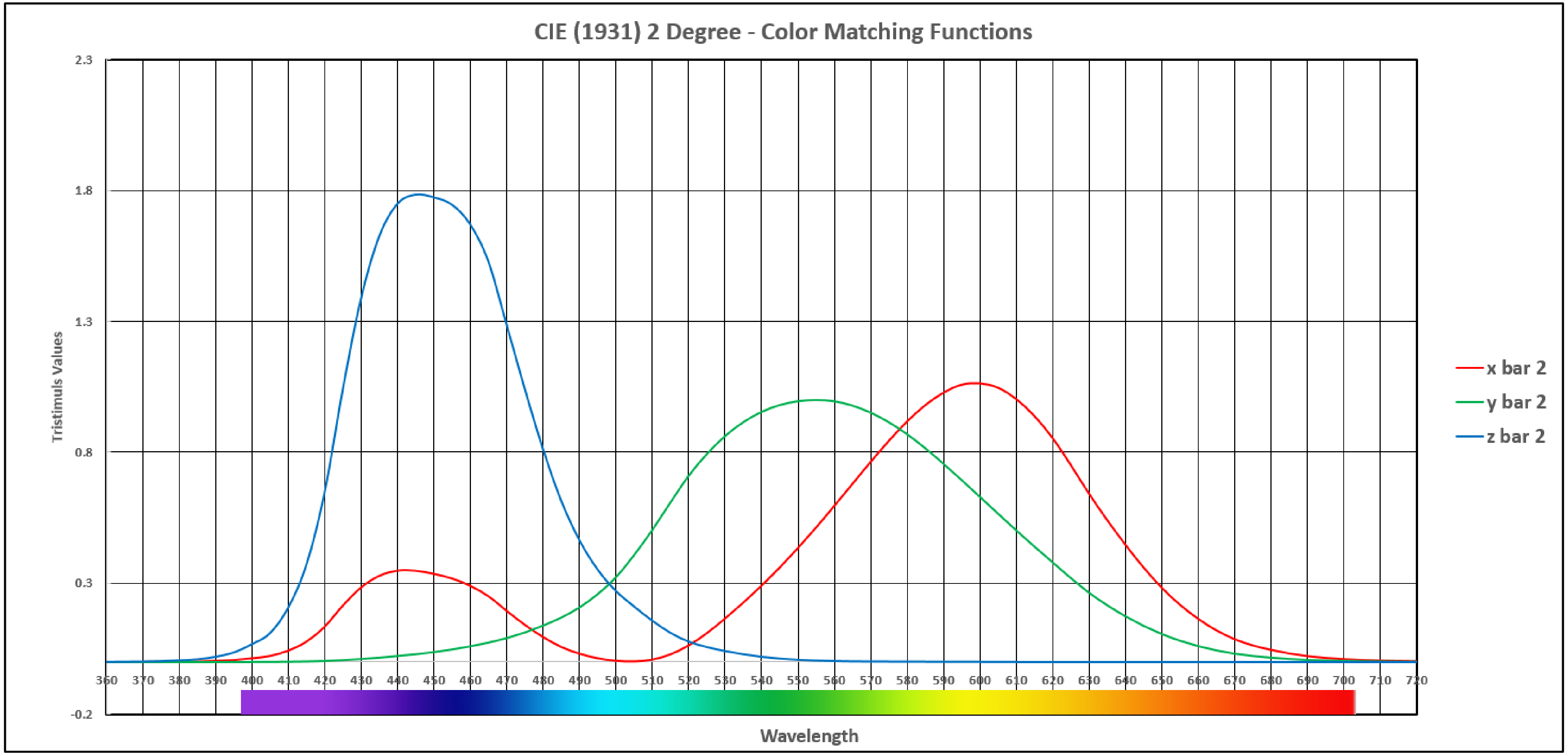

CIE Luminosity Function - *V(λ)*

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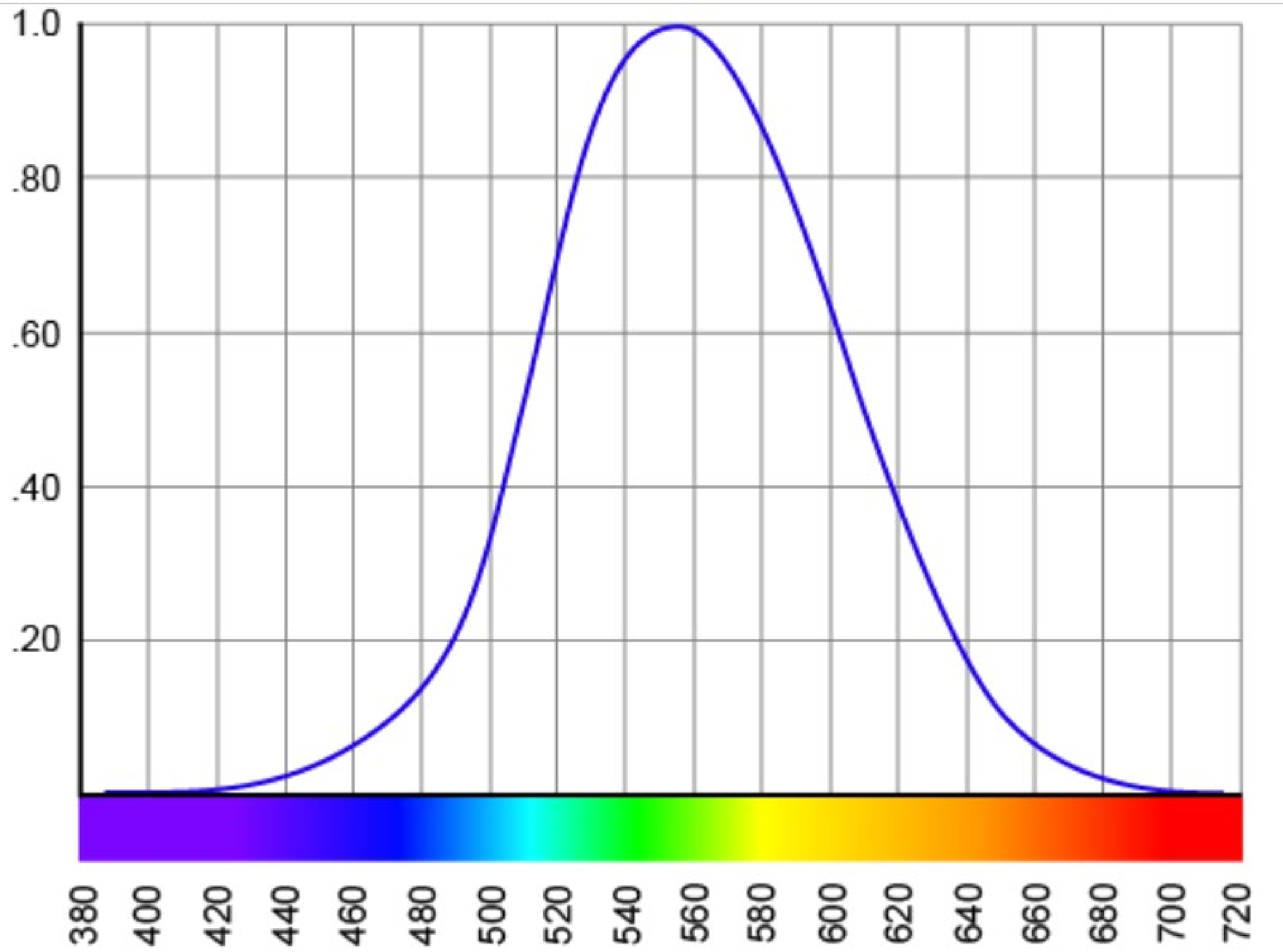

The CIE photopic luminosity function *V*(*λ*) was established by the CIE and describes the average spectral sensitivity of human visual perception of brightness.

Some wavelengths can be seen more easily than others. We see green light around 550 nm much more easily than at any other wavelengths. Luminosity is the property of light by which we define how easily we can see it.

The y (y bar) color matching function of the CIE Standard Observer was made equivalent to the CIE Luminosity function.

A Second Experiment

Repeated in 1964 with different field of view and lamps

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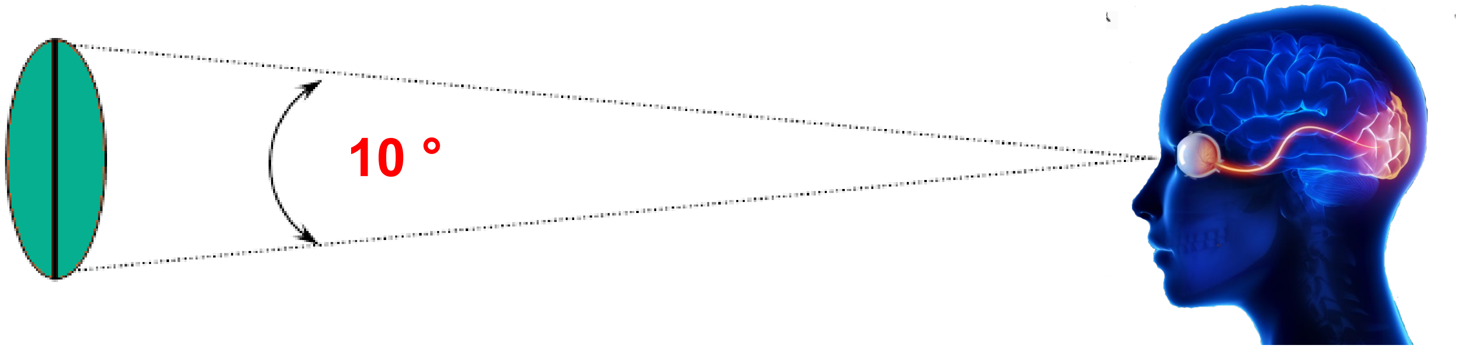
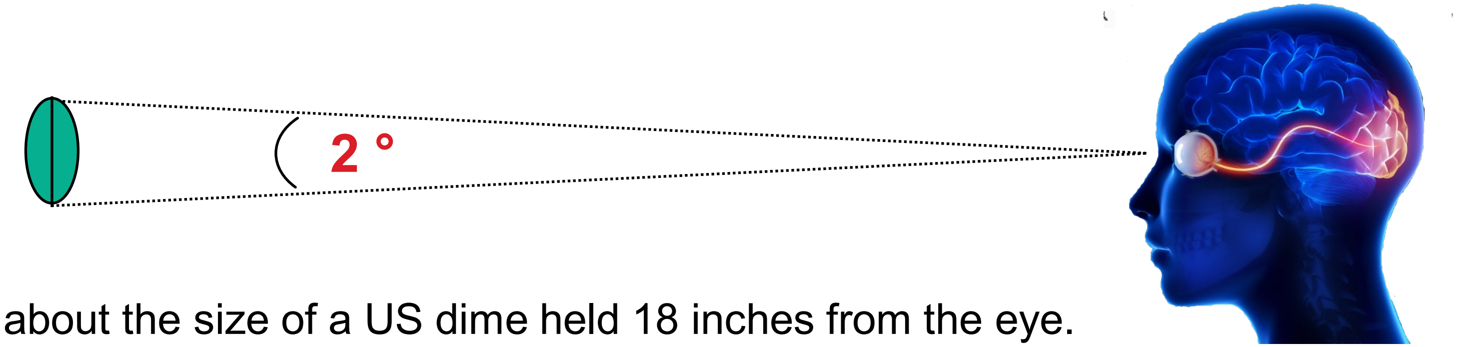
In 1964 the experiment was repeated using larger target areas and different source lamps.



The 10° field of view is about 27 times the area of the 2° field of view.



A 2° field of view is about the size of a US dime held 18 inches from the eye.

1964 10° – Standard Observer

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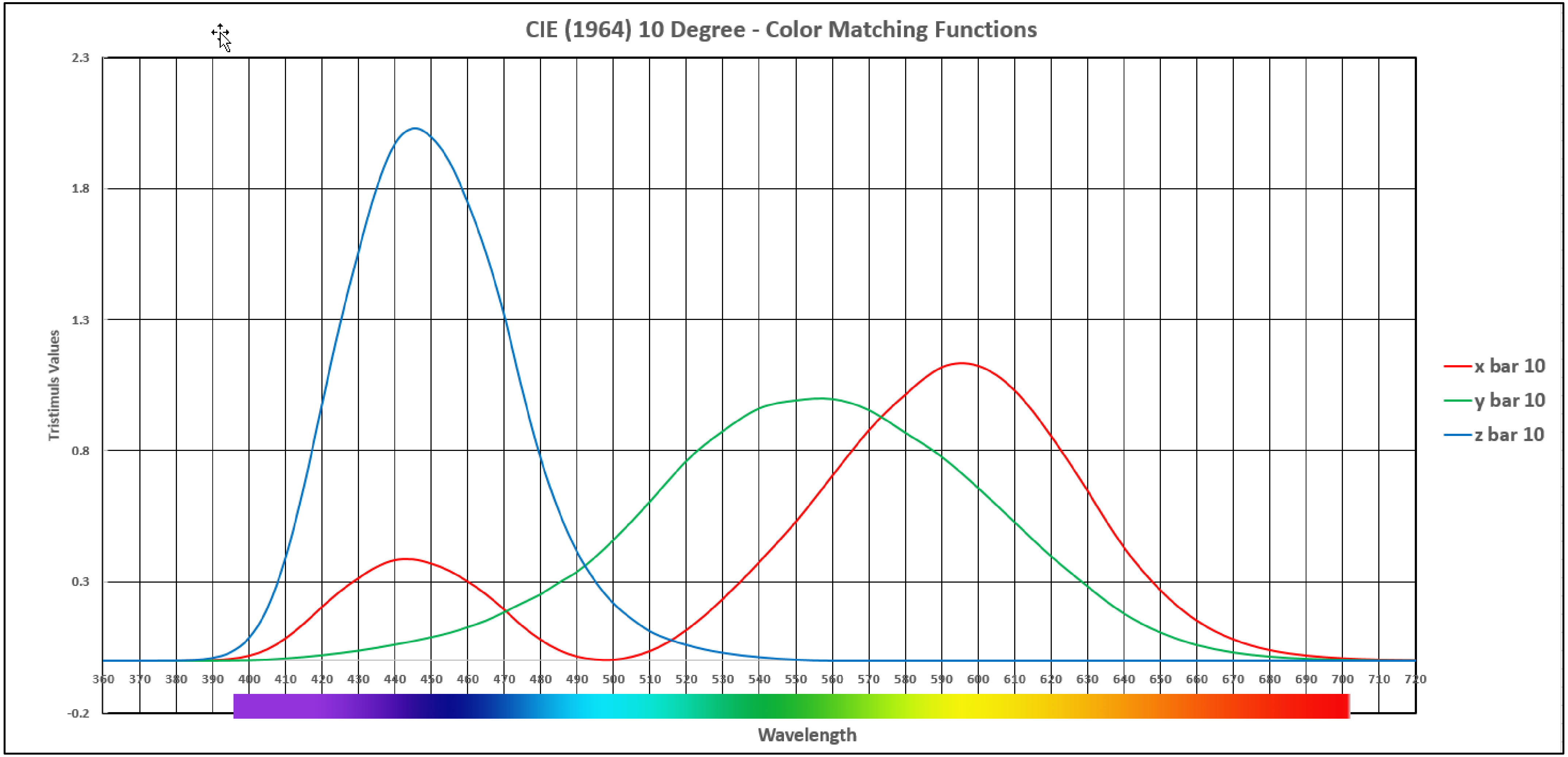

1931 2° & 1964 10° Standard Observers

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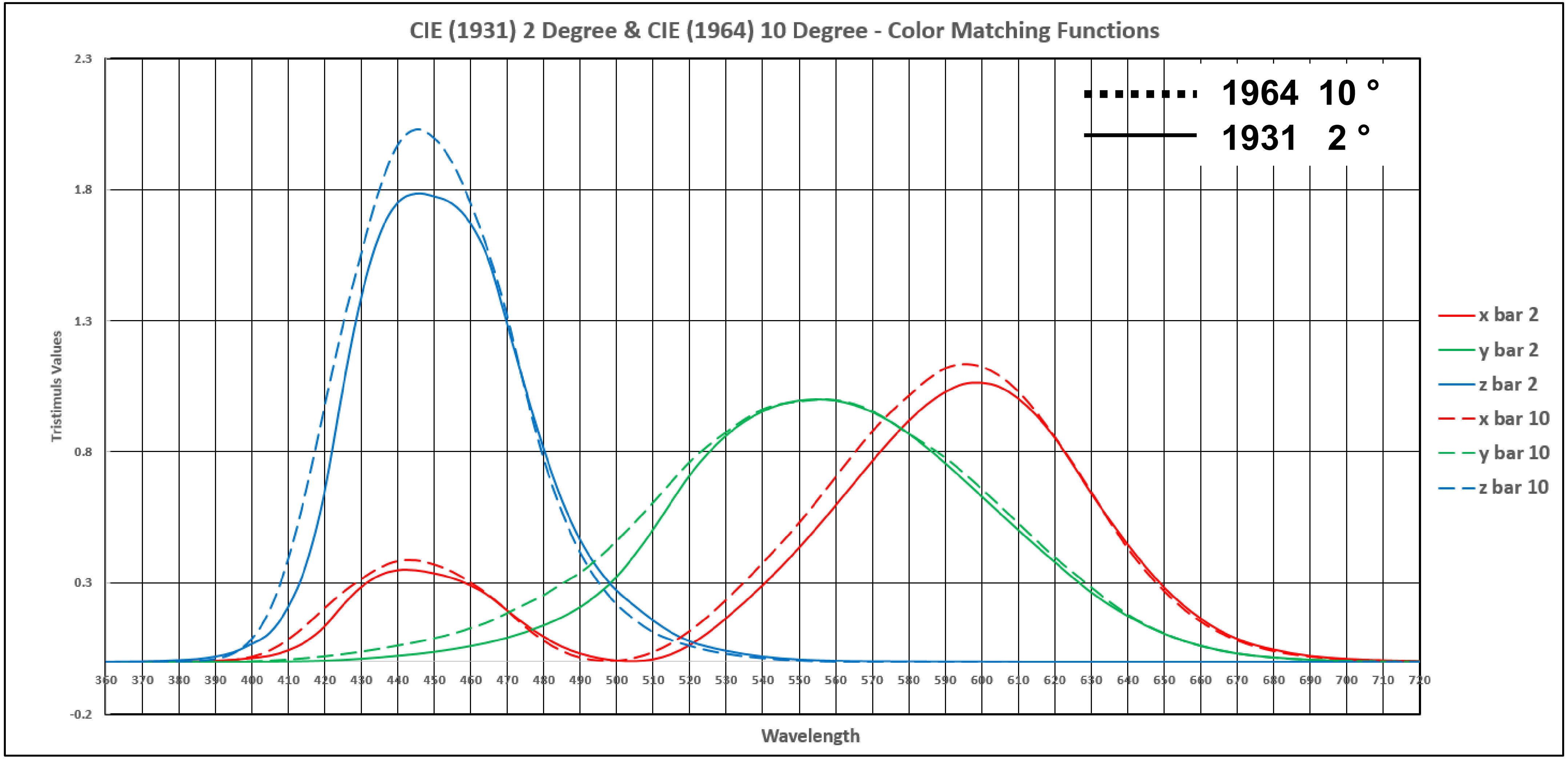

A Colorimetric Description

Defining a numerical system for color perception

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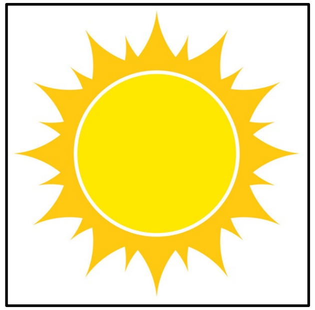
We have described the visual color perception process by showing how the light source, object and observer are together responsible for color perception.



Natural Daylight

x

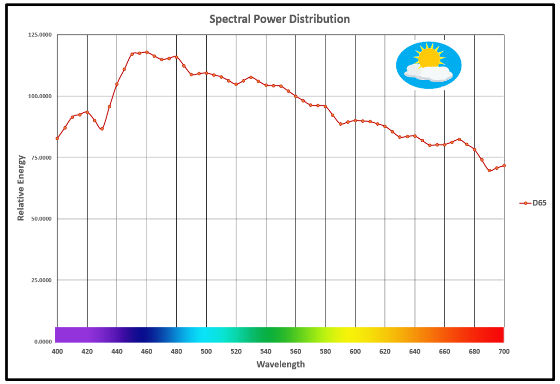
Object (Apple)

x

Human Observer

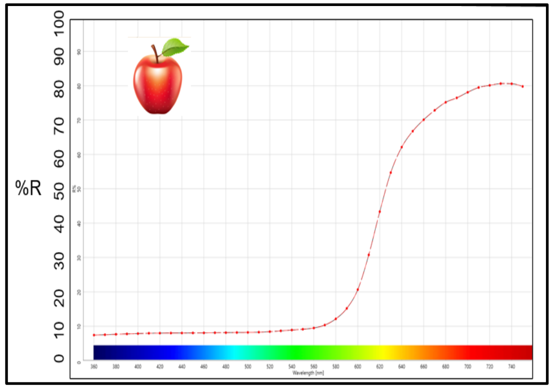
= **Color Perception**

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



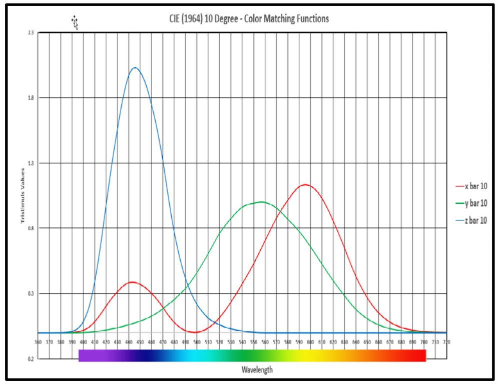
Daylight Illuminant
Numerical Data

x



Reflectance Curve
Numerical Data

x



CIE Standard Observer
Numerical Data

= **Colorimetric Description**

Tristimulus Values

Amounts of imaginary red, green and blue light to match color

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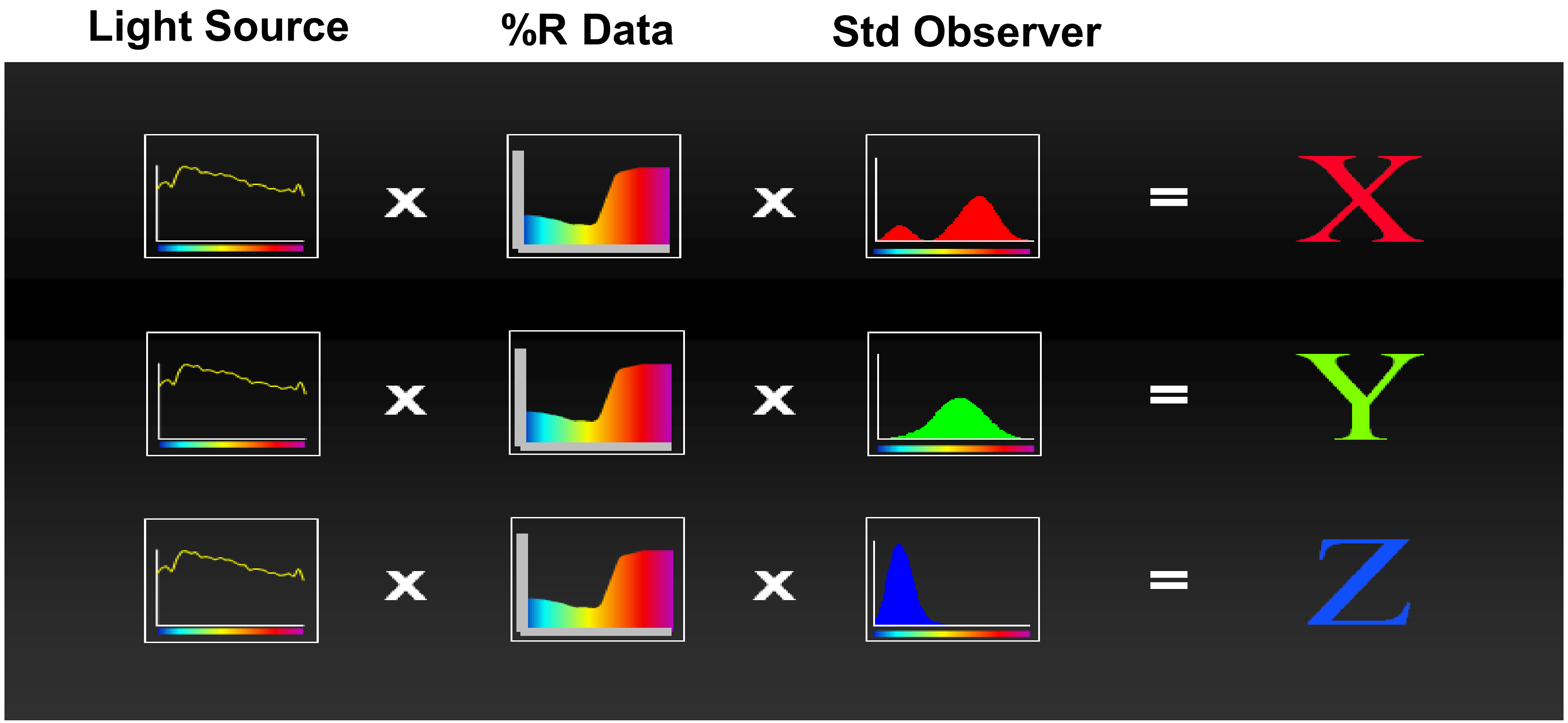
Tristimulus values are computed wavelength by wavelength, by multiplying illuminant, object, & observer data, at each wavelength, then adding the results.



Tristimulus Calculation

Sum of Product of Illuminant, Std Observer Data, and %R at λ

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$$X = K \sum_{380}^{780} P(\lambda)\ x(\lambda)\ R(\lambda)$$

$$Y = K \sum_{380}^{780} P(\lambda)\ y(\lambda)\ R(\lambda)$$

$$Z = K \sum_{380}^{780} P(\lambda)\ z(\lambda)\ R(\lambda)$$

$$K = 100/\left(\sum_{380}^{780} P(\lambda)\ y(\lambda)\right)$$

Where:

$P(\lambda)$ = Light Energy

$x(\lambda)$ = red std observer data

$y(\lambda)$ = green std observer data

$z(\lambda)$ = blue std observer data

$R(\lambda)$ = Sample %R

K = normalizing factor

Illuminant and Observer Data

ASTM E308 Tables

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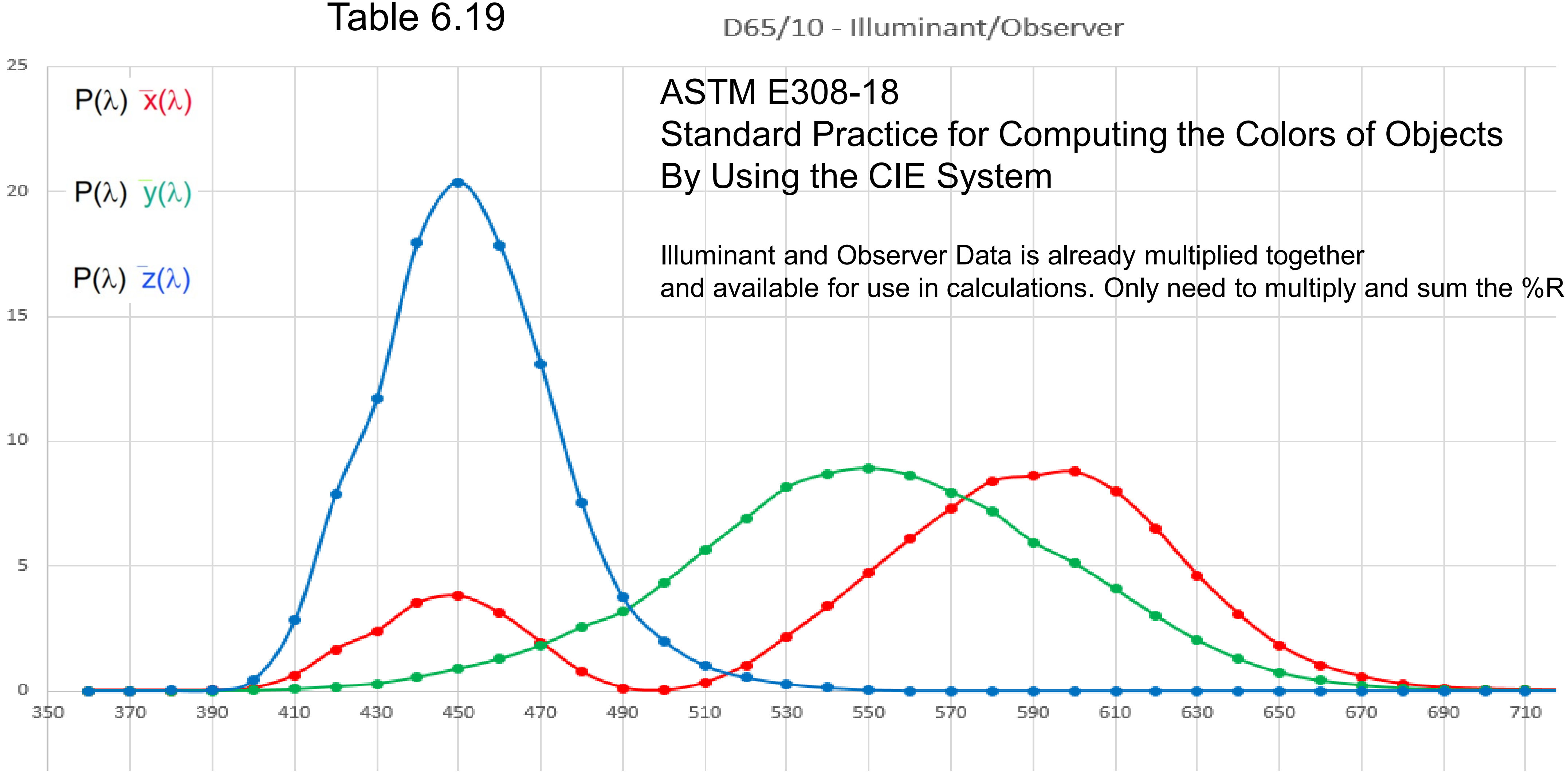
Table 6.19



ASTM E308-18
Standard Practice for Computing the Colors of Objects
By Using the CIE System

Illuminant and Observer Data is already multiplied together and available for use in calculations. Only need to multiply and sum the %R data.

What the XYZ Means

Having the Standard Observer Match the Apple Under Daylight Illumination

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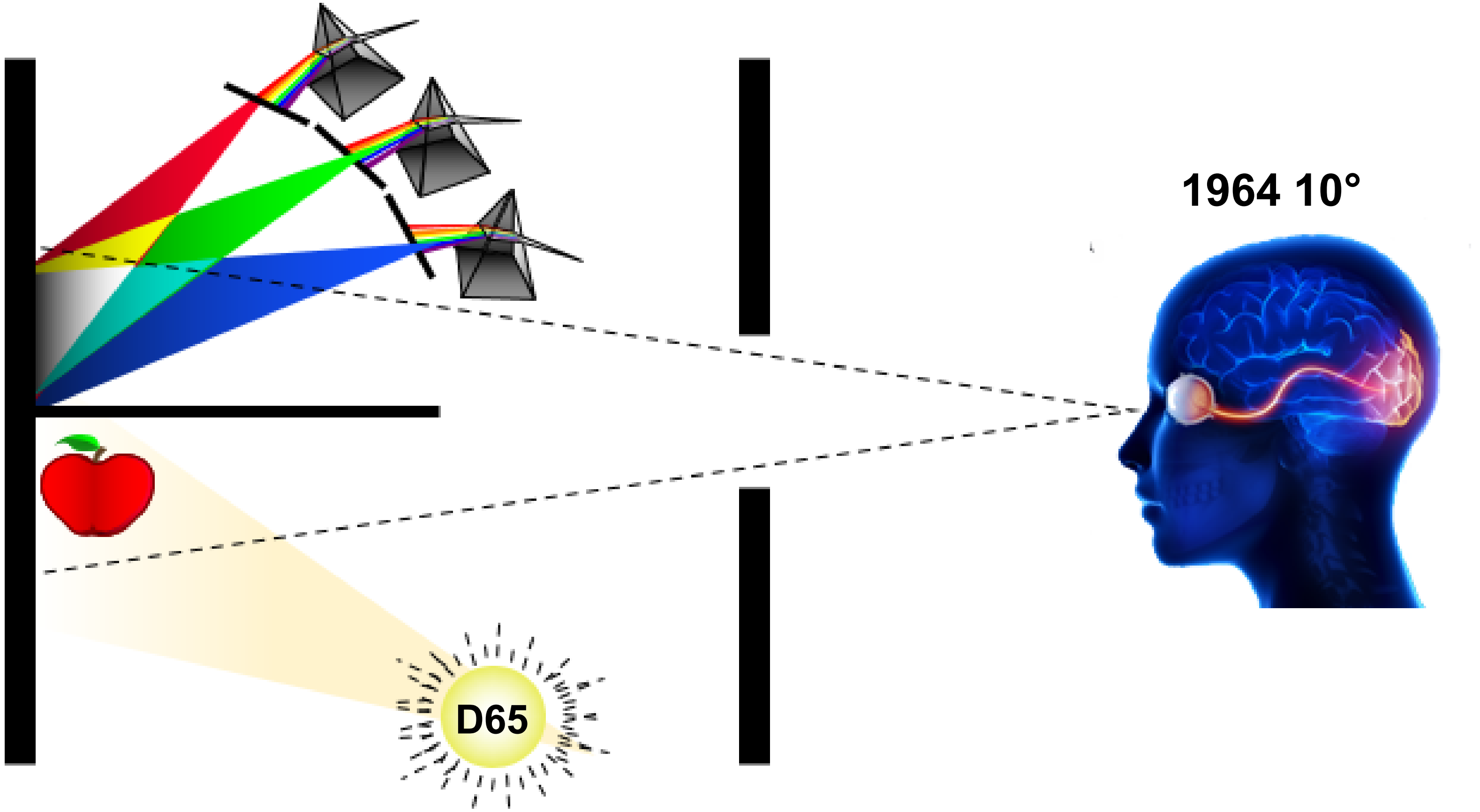
X = 58.1 Y = 36.0 Z = 5.9



XYZ – D65/10°

Tristimulus Values of the Apple Under D65 with 1964/10° Observer

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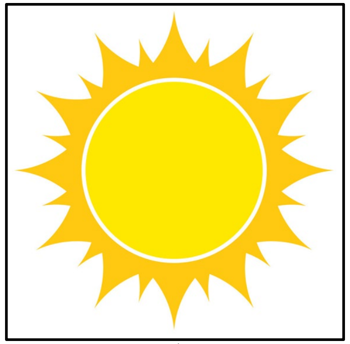
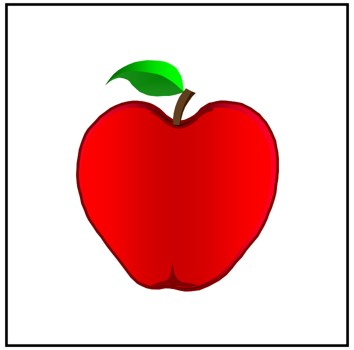
D65 Illuminant



%R of Apple



1964 10° Std Obs

X 58.1
Y 36.0
Z 5.9

XYZ D65/10°   XYZ A/10°

Changing Illuminant Changes the Amount of Light Required to Match

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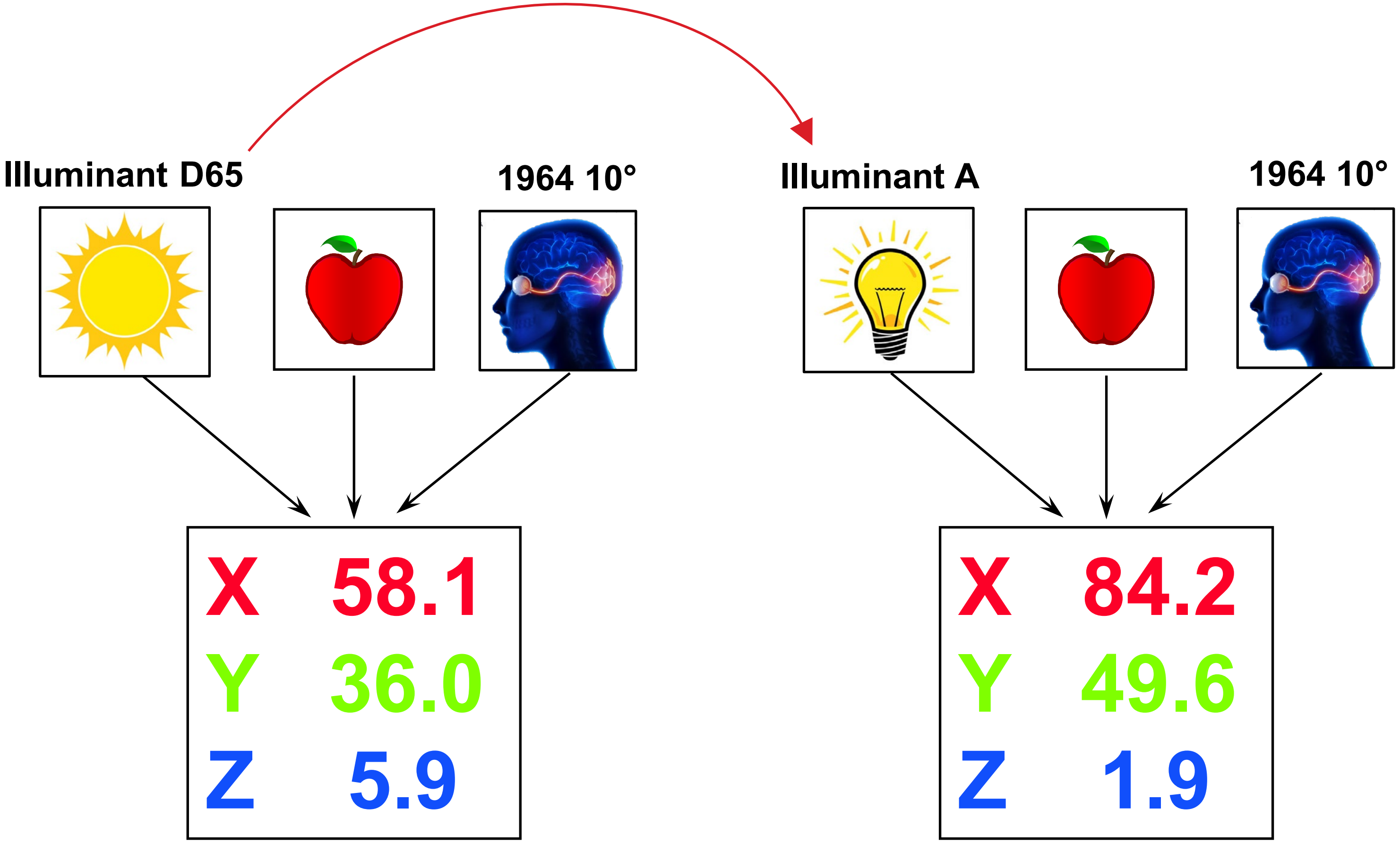

Using Tristimulus Values

Colors with Equal XYZ Values Visually Match

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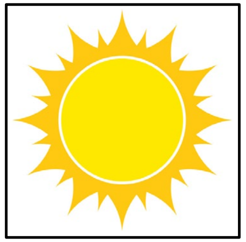
D65 Illuminant



1964 10° Std Obs

X	28.5
Y	30.0
Z	32.6

X	28.5
Y	30.0
Z	32.6

The XYZ values are equal for the 2 samples using Illuminant D65 and the 1964 10° Observer.

These 2 samples should also be a visual match under a D65 type light source and a normal observer.

Metamerism

Colors with Different %R Curves May Have Equal XYZ Values

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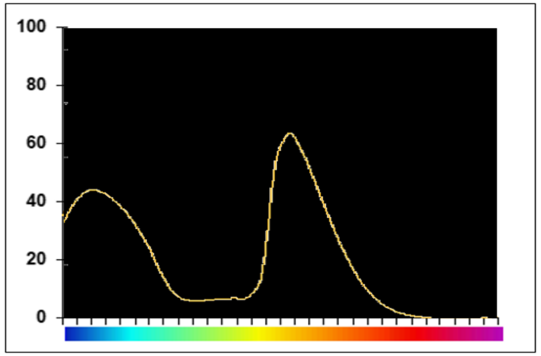
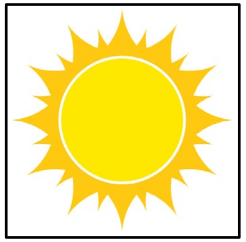
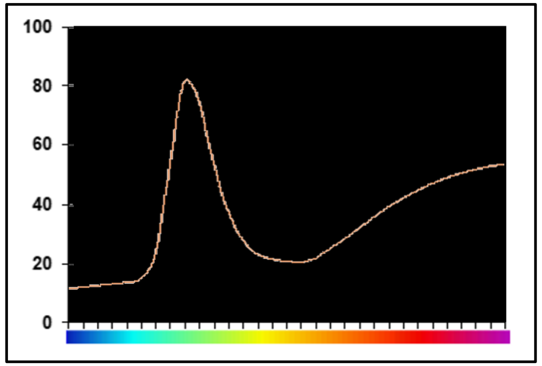


X 28.5
Y 30.0
Z 32.6

D65 Illuminant



1964 10° Std Obs



X 28.5
Y 30.0
Z 32.6

The XYZ values are equal for the 2 samples using Illuminant D65 and the 1964 10° Observer.

These 2 samples may be a visual match under a D65 type light source and a normal observer. Because of the spectral difference however, the sample pair may be a mismatch under a different illuminant or to a different observer. This is called metamerism.

Metamerism

The Illuminant Has Changed from D65 to A (Incandescent)

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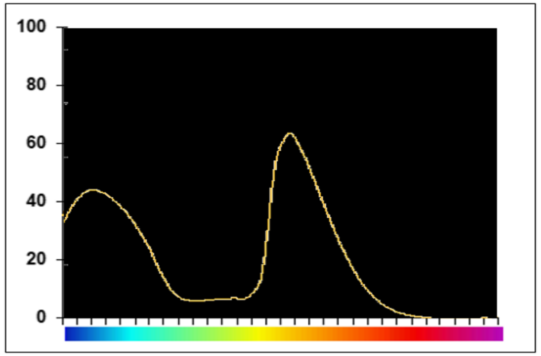
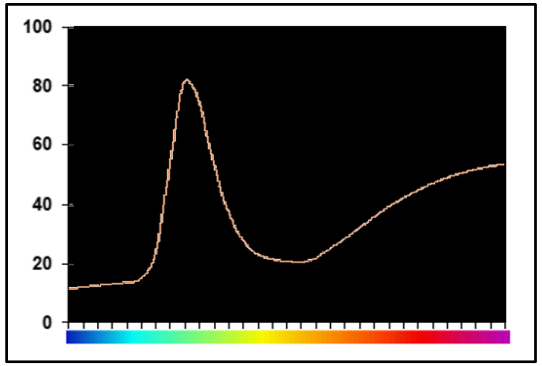


Illuminant A

1964 10° Std Obs



X	27.7
Y	30.6
Z	9.50

X	36.3
Y	29.8
Z	12.2

The XYZ values are now different for the 2 samples using Illuminant A and the 1964 10° Observer.

These 2 samples will not be a visual match under an incandescent type light source and a normal observer. Because of the spectral difference the sample pair will be a mismatch under a this different illuminant. The samples are called a metameric pair.

Metamerism

Match Under D65/2

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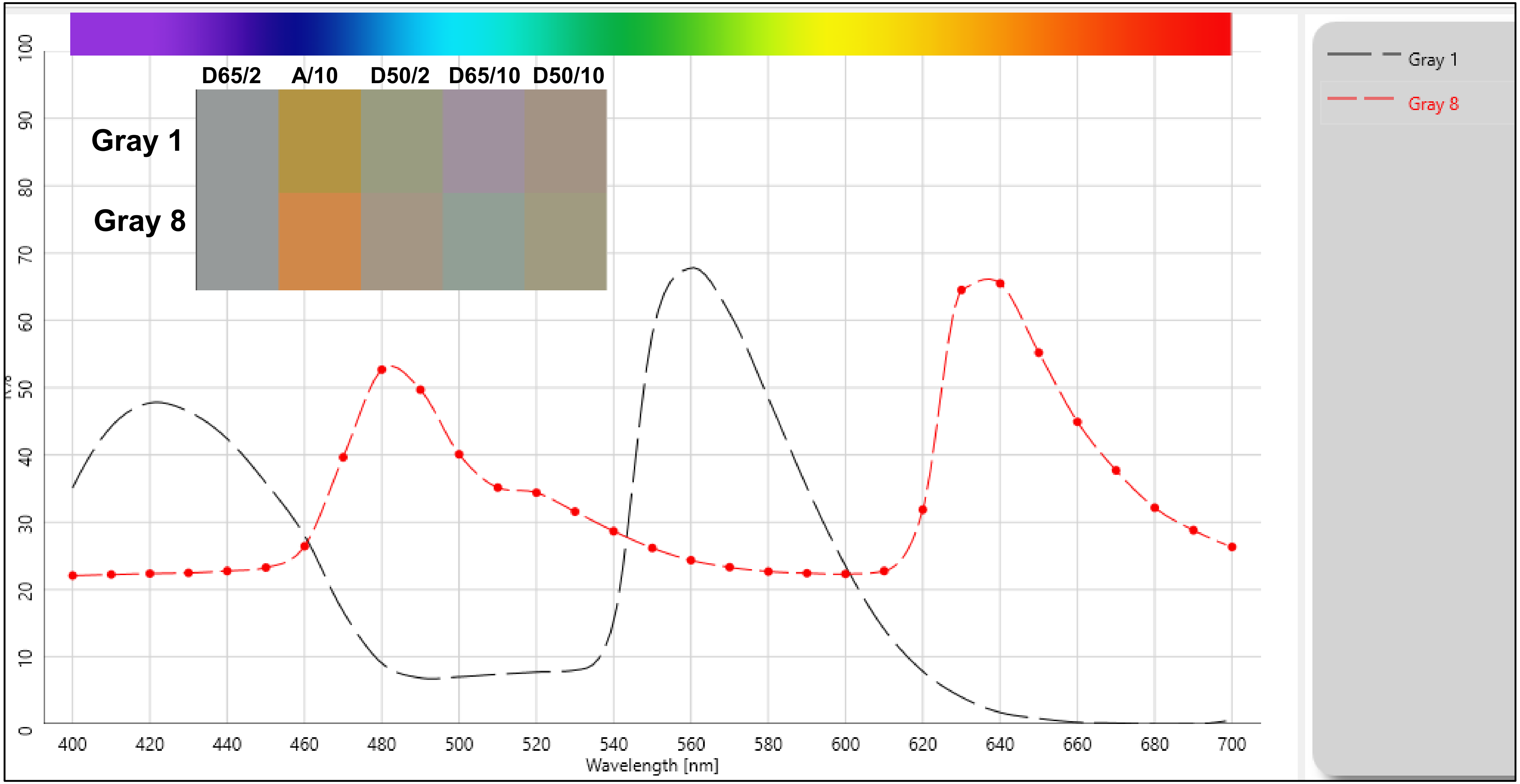

Metamerism

Simple Gray and Complex Gray

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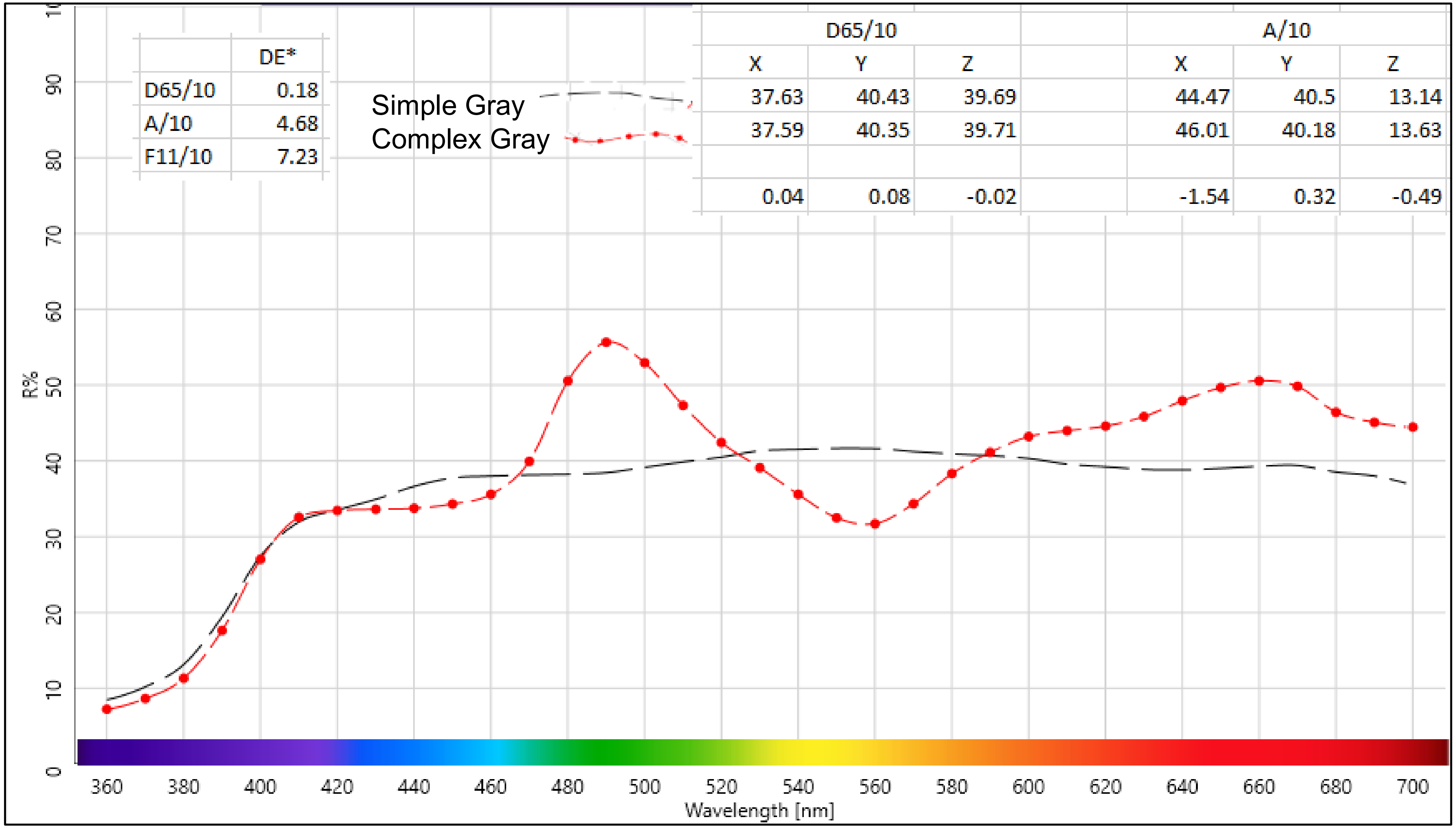

	DE*
D65/10	0.18
A/10	4.68
F11/10	7.23

D65/10				A/10		
X	Y	Z		X	Y	Z
37.63	40.43	39.69		44.47	40.5	13.14
37.59	40.35	39.71		46.01	40.18	13.63
0.04	0.08	-0.02		-1.54	0.32	-0.49

Chromaticity Diagram

Mapping Color Coordinates

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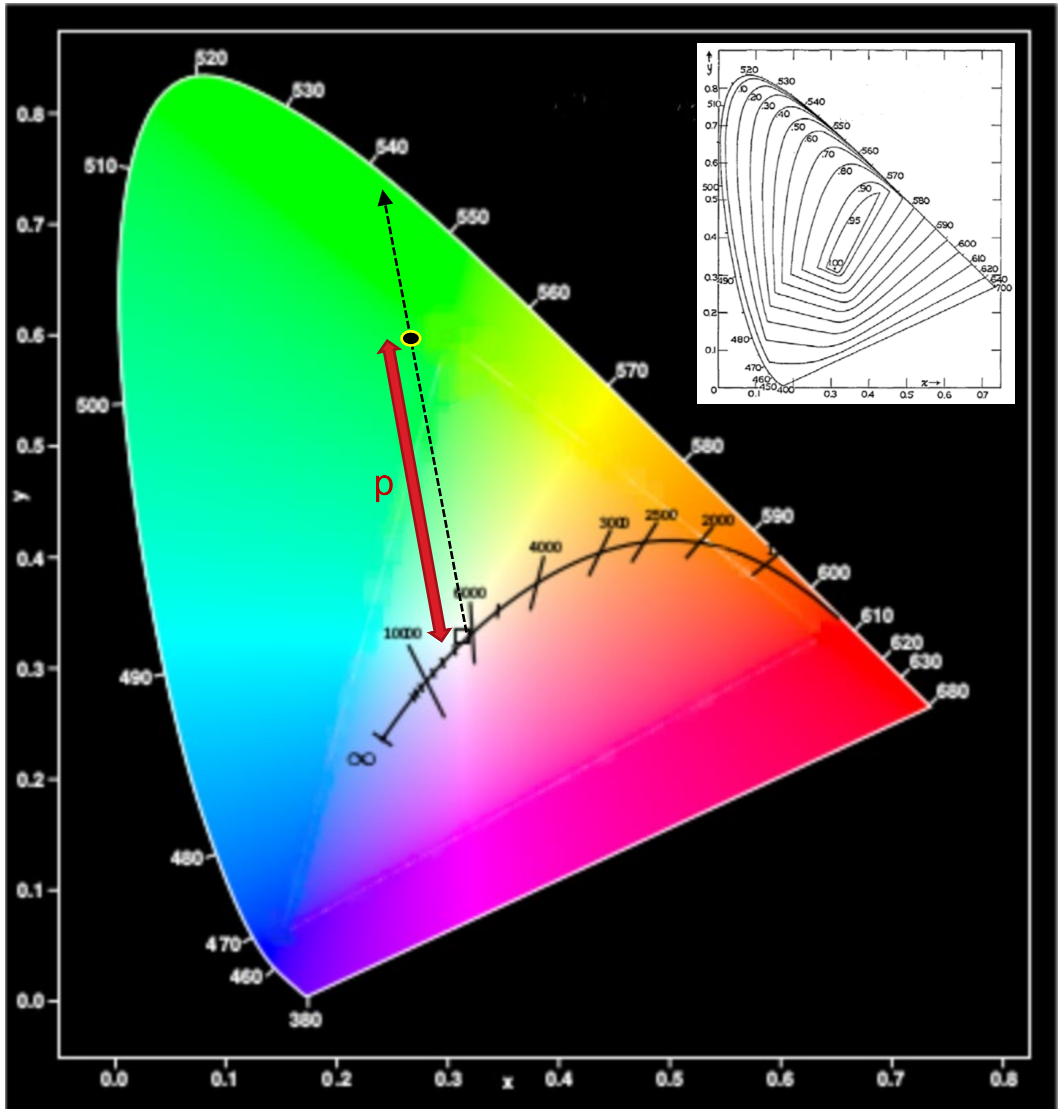

Chromaticity Coordinates

$$x = X / (X + Y + Z)$$

$$y = Y / (X + Y + Z)$$

$$z = Z / (X + Y + Z)$$

$$x + y + z = 1.00$$

The chromaticity coordinates map the color with respect to hue and saturation on the two-dimensional CIE Chromaticity Diagram.

CIE xyY Color Space

CIE Chromaticity Diagram
Chromaticity Coordinates

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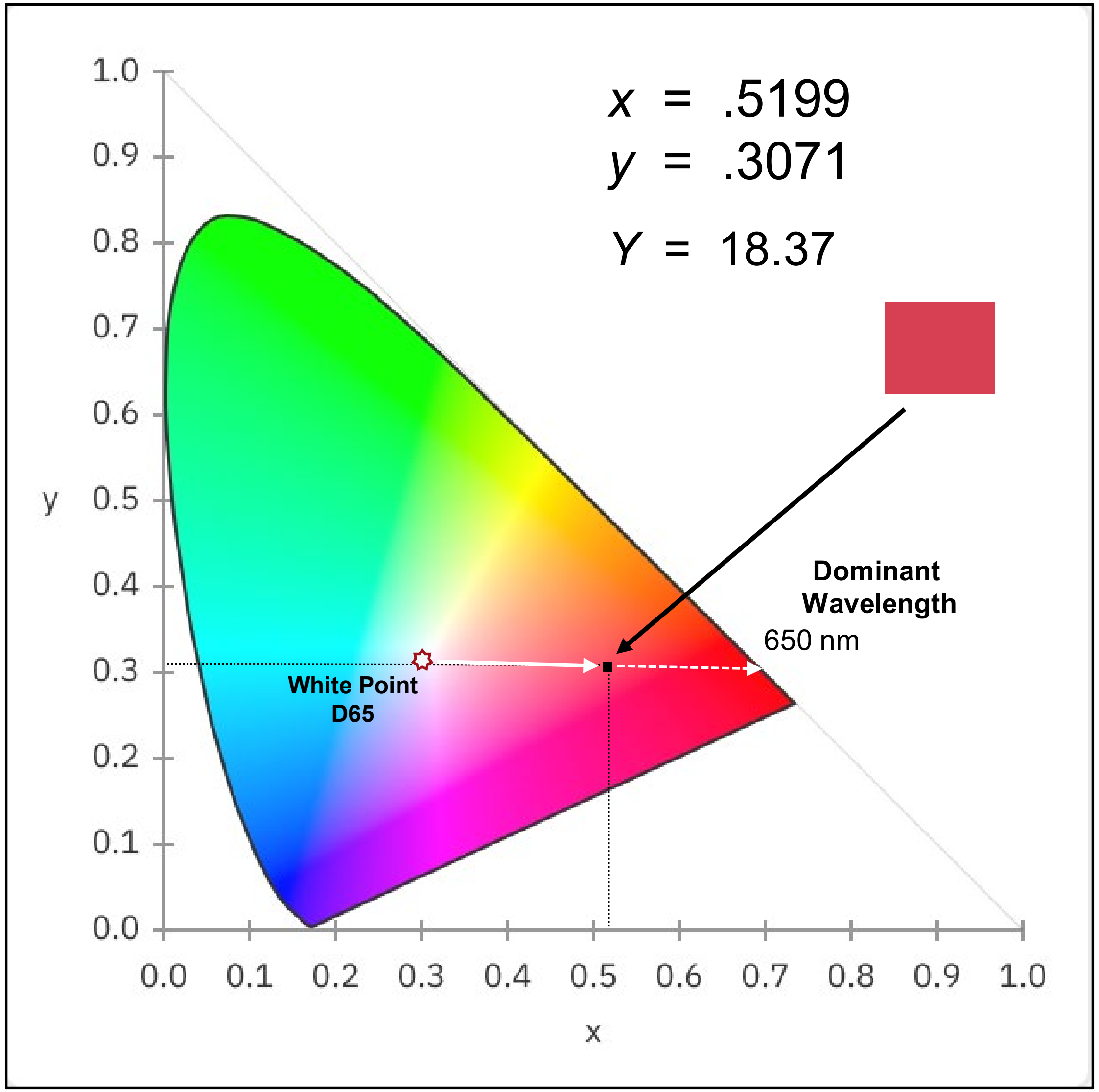

Tristimulus Values of Red Sample – D65/2

X = 31.10 Y = 18.37 Z = 10.35

Chromaticity Coordinates

x, y = (.5199, .3071)

CIE xyY Color Space

CIE xyY = (.5199, .3071, 18.37)

McAdam's Ellipses

The Search a Uniform Color Space

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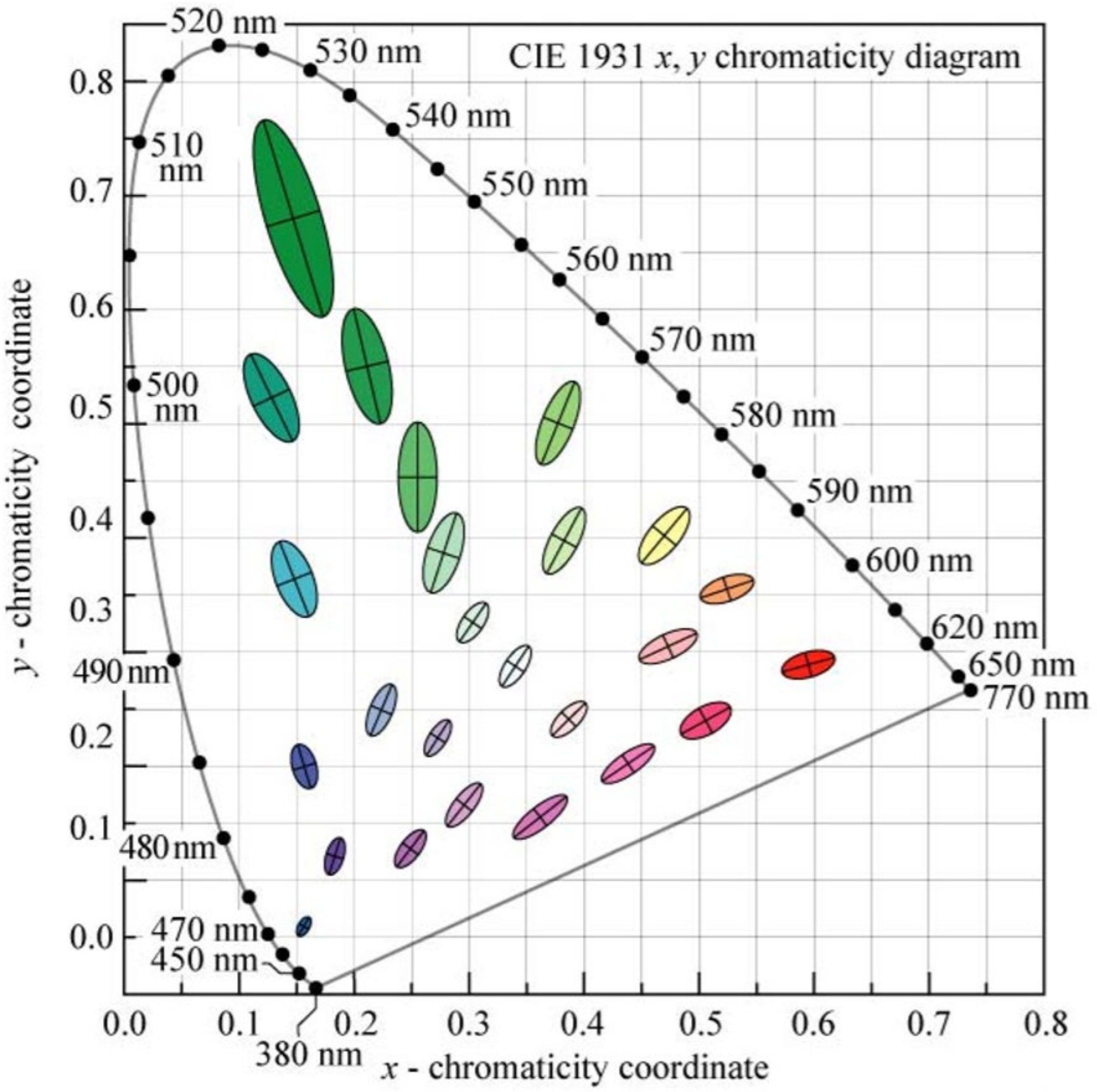

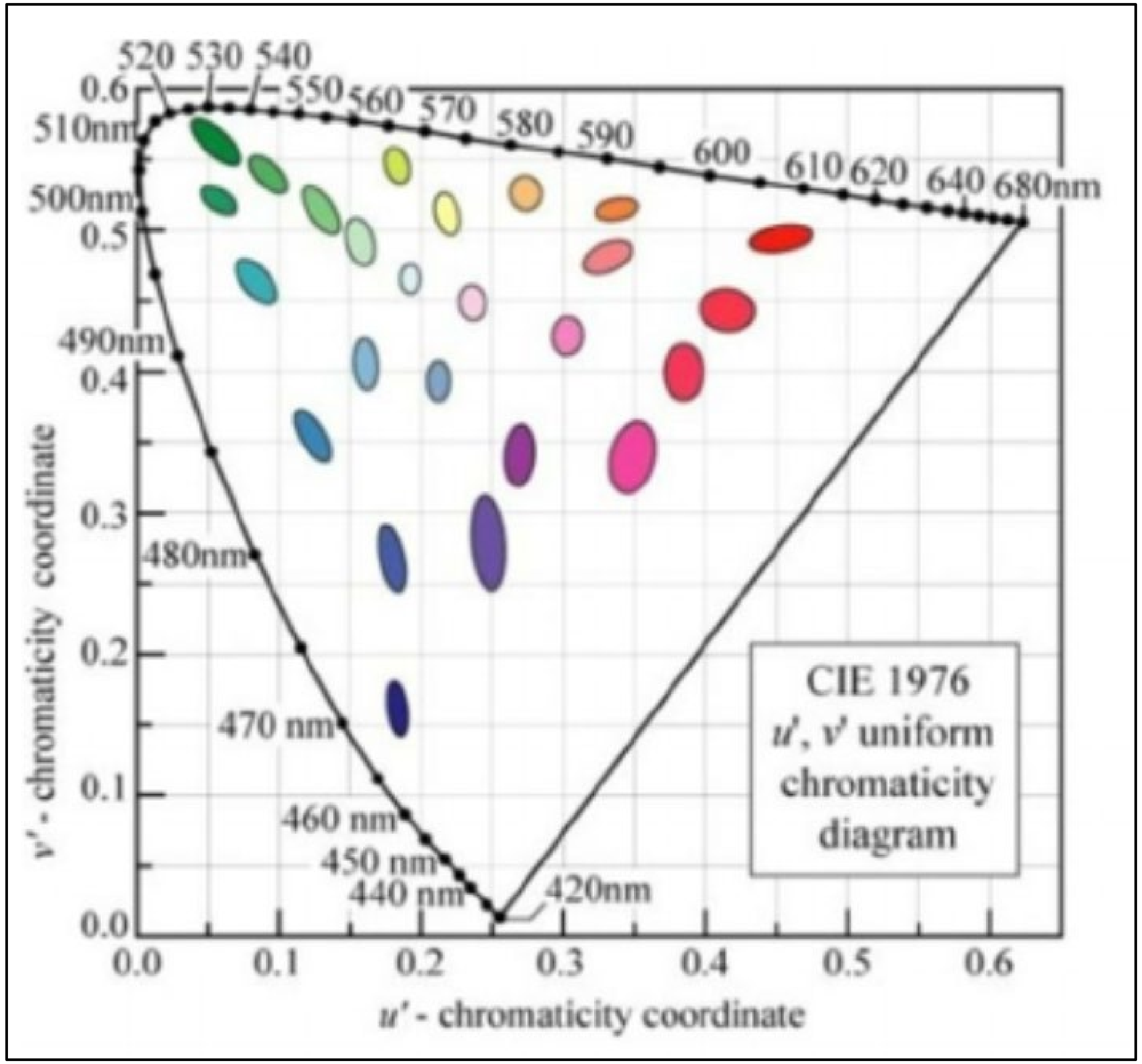

A Natural Color Language

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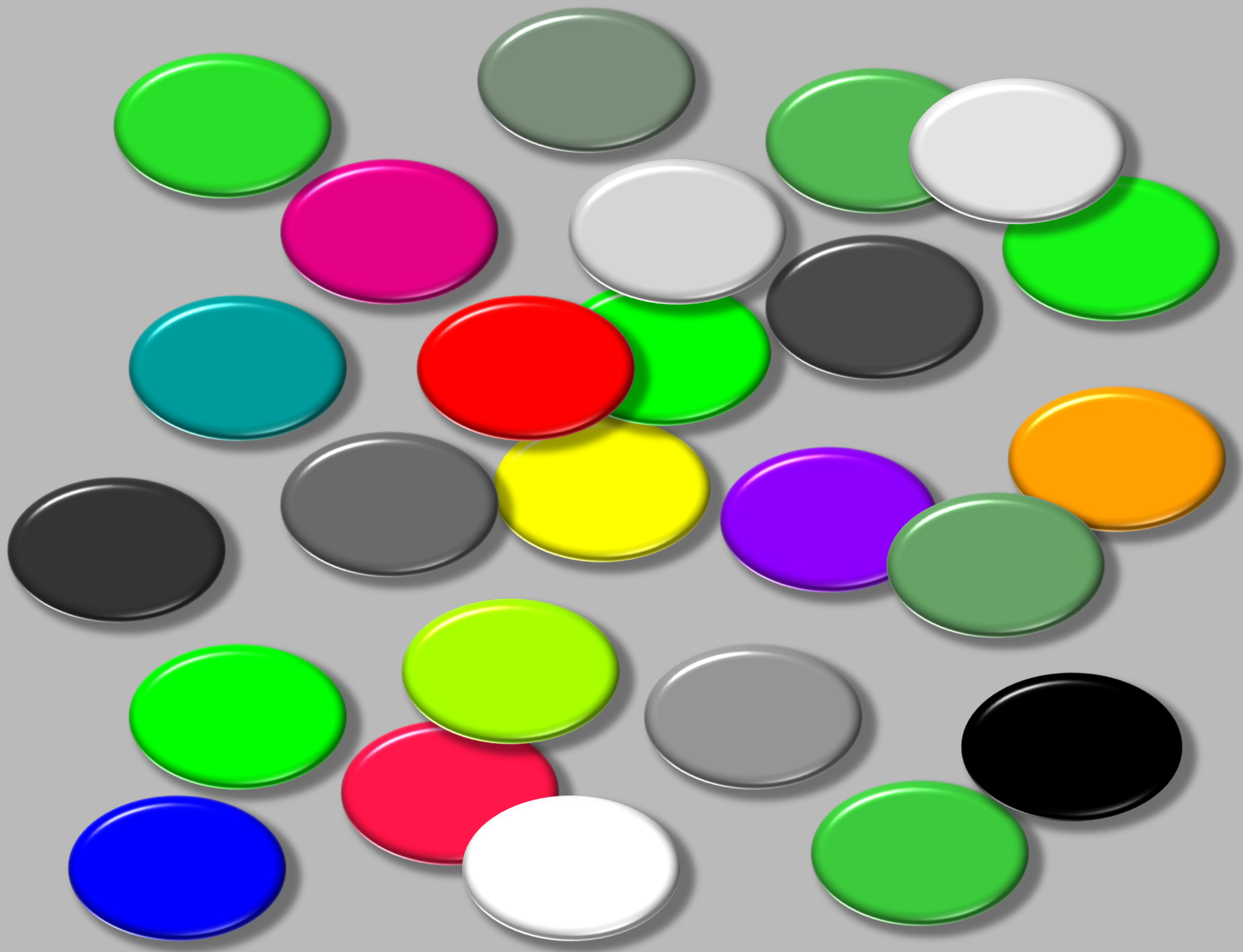
Imagine placing these color chips in order



A Natural Color Language

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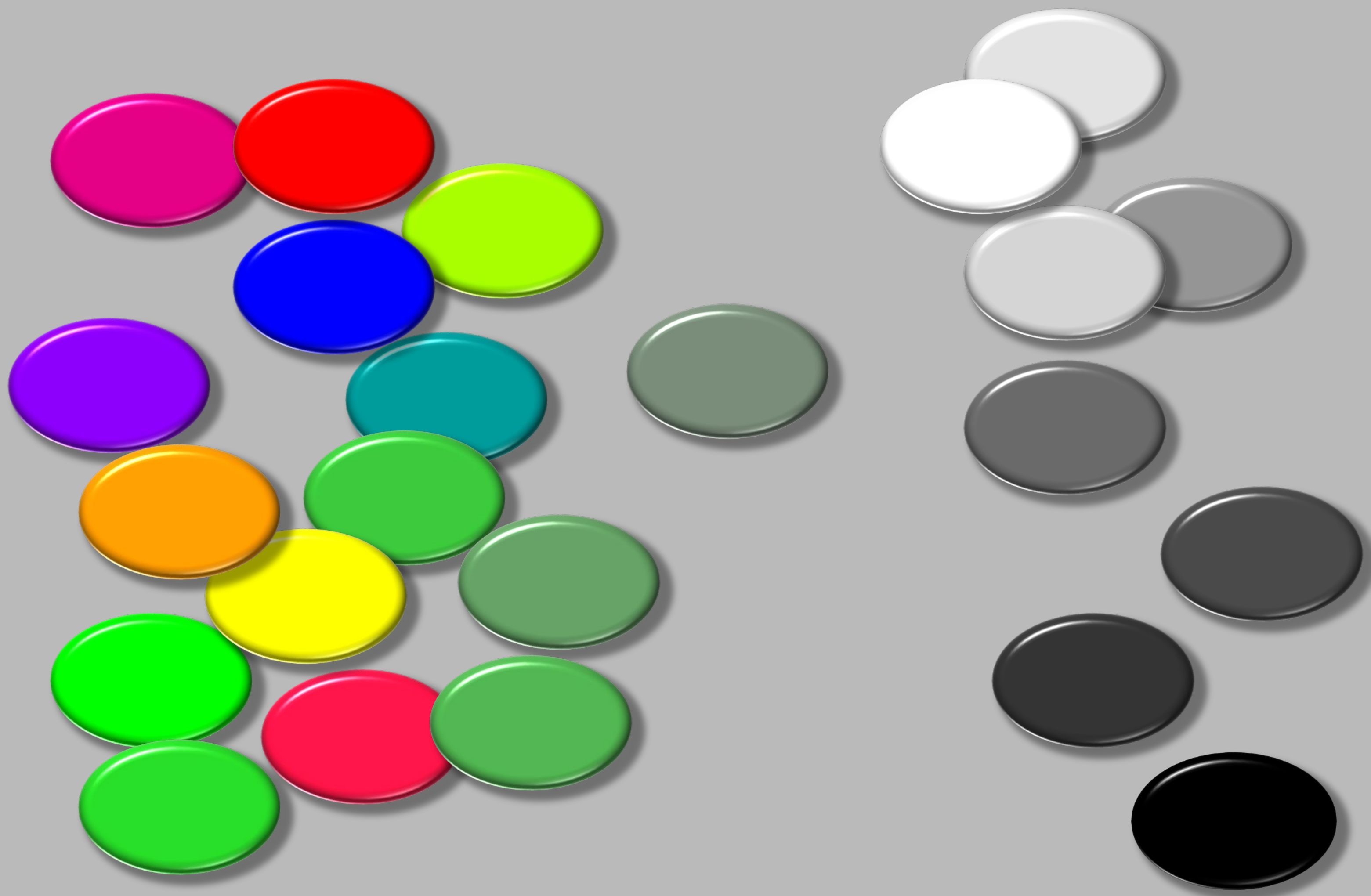
You might start by separating the gray or neutral chips



A Natural Color Language

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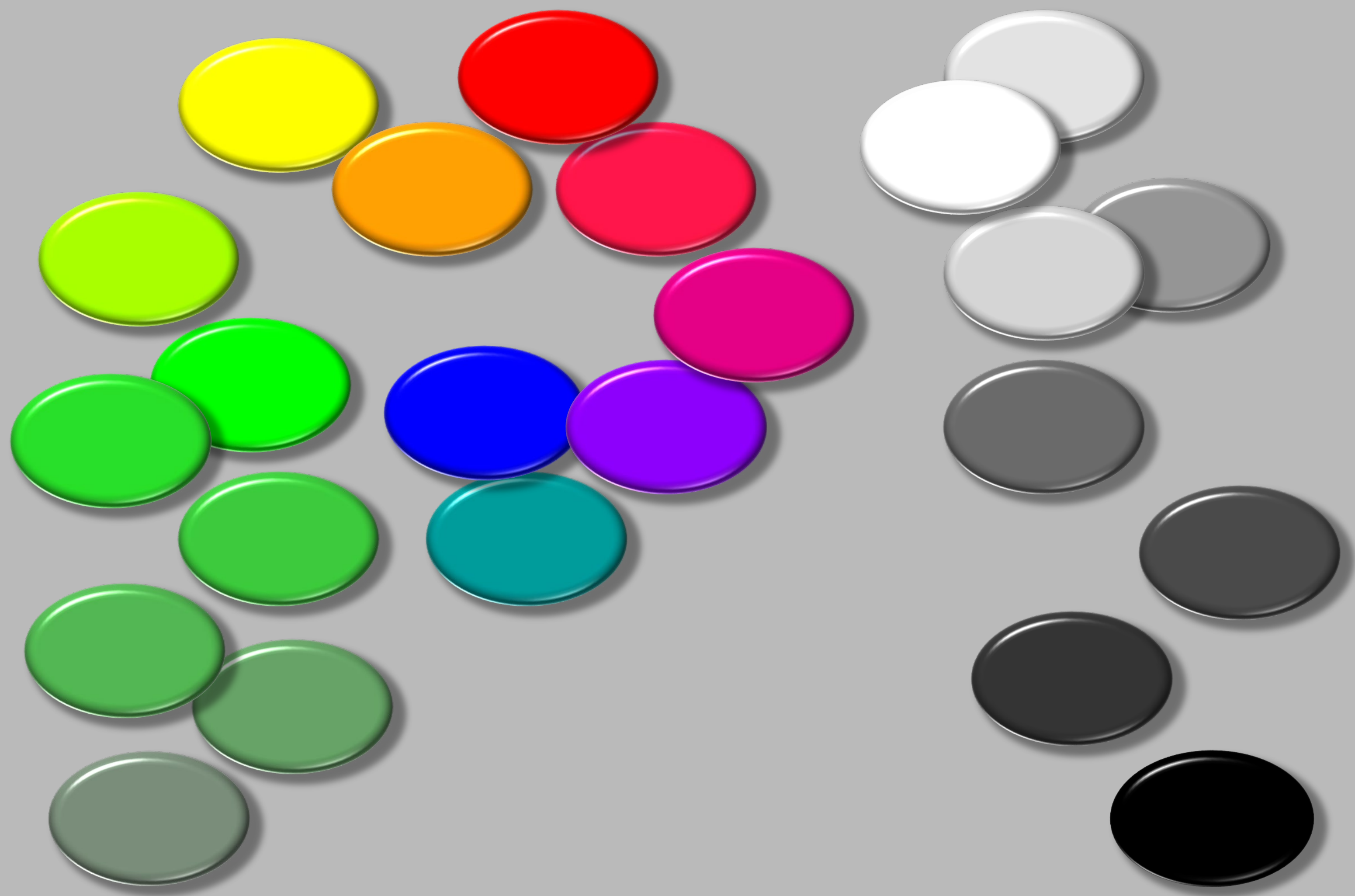
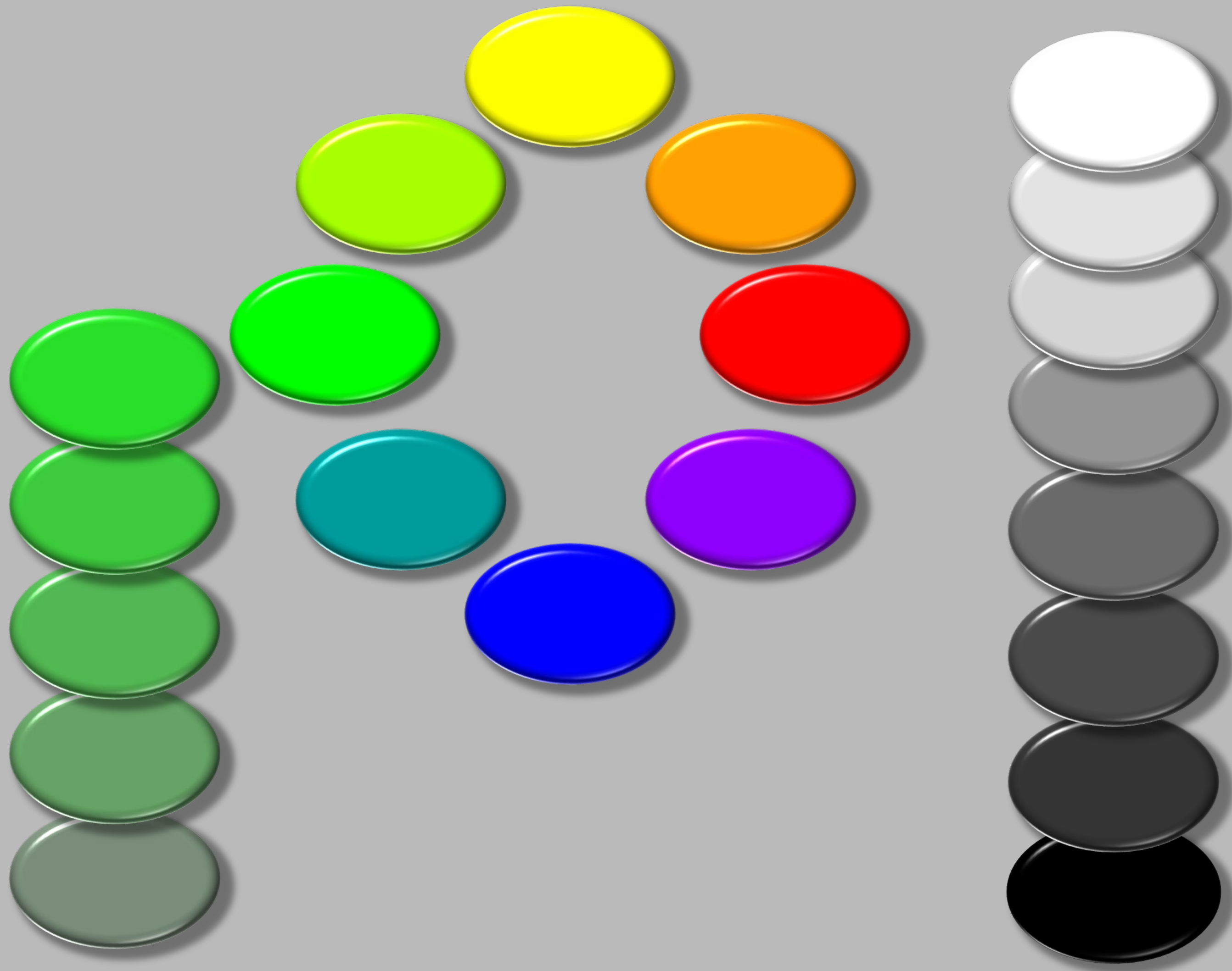
You then
might
separate
similar
shades



A Natural Color Language

You could then finally arrive at an arrangement like this



A Natural Color Language

Hue, Chroma, Lightness

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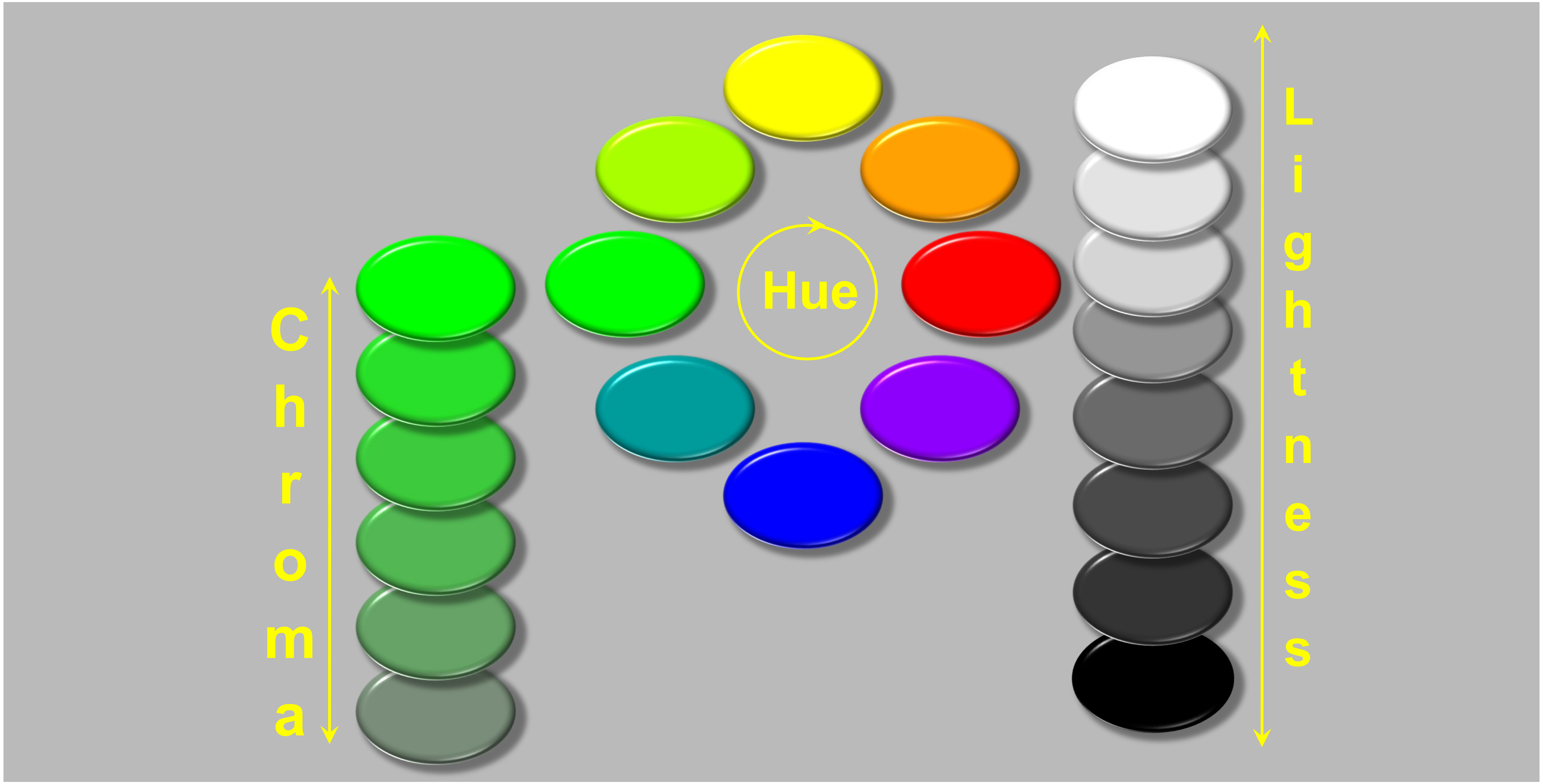

3 Dimensions of Color

Hue, Chroma, Lightness

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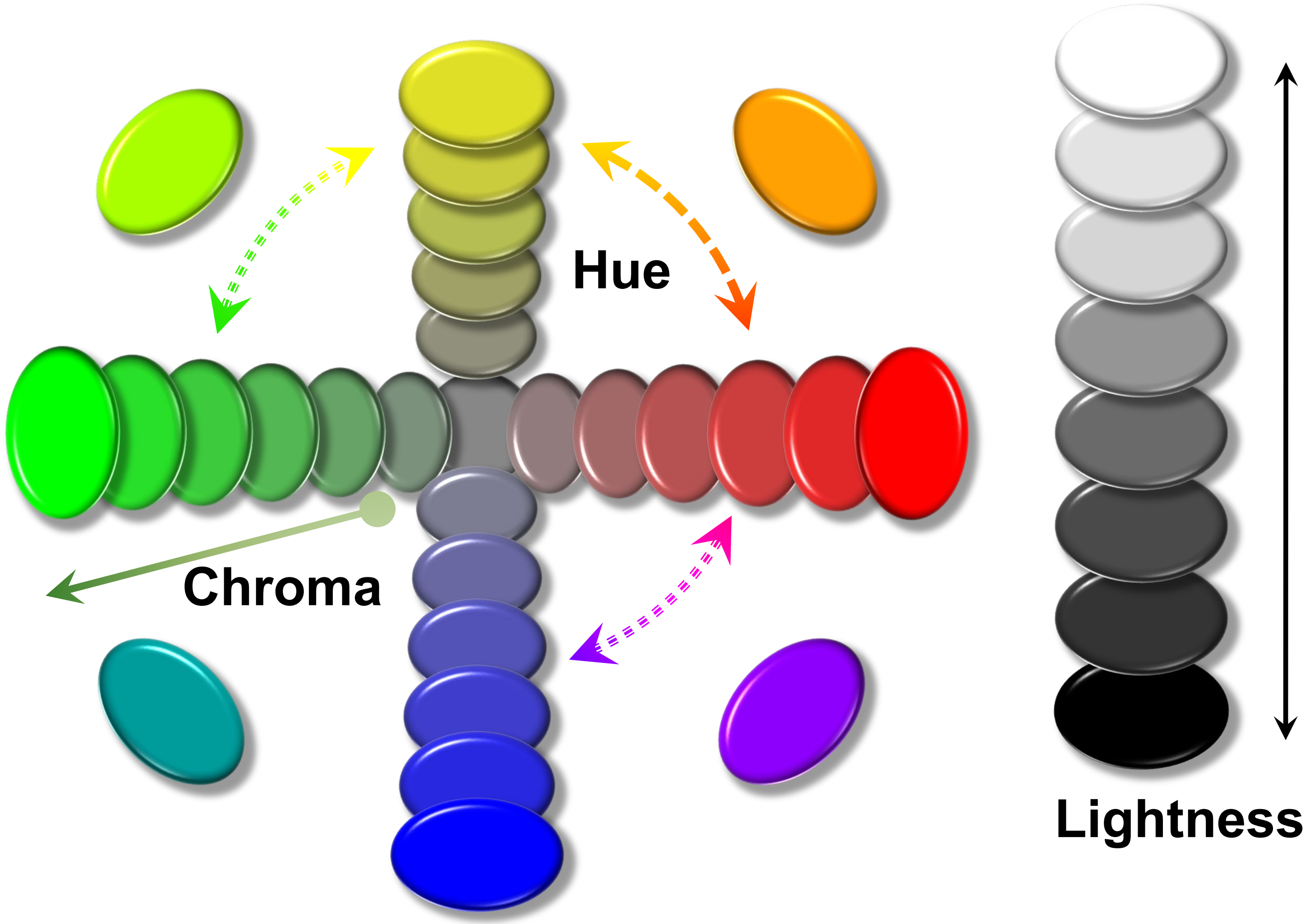
Hue
Red, Blue, Yellow, etc.
Greenish, Redder

Chroma
Saturation
Dull
Strong
Weak
Vivid
Pale

Lightness
Light
Dark
Bright
Dim



Webinar – Final Comments

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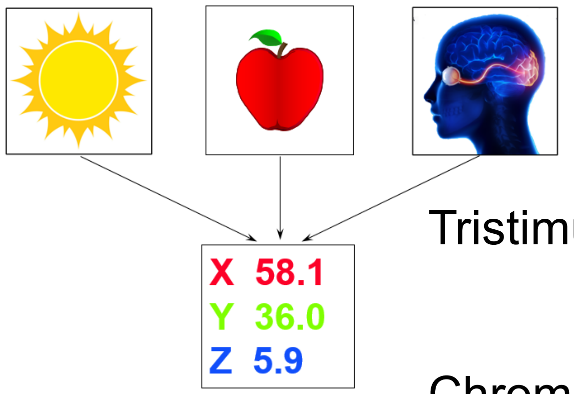
We have described the visual color perception process and defined a colorimetric description in these last 2 webinars.

Light Object Observer

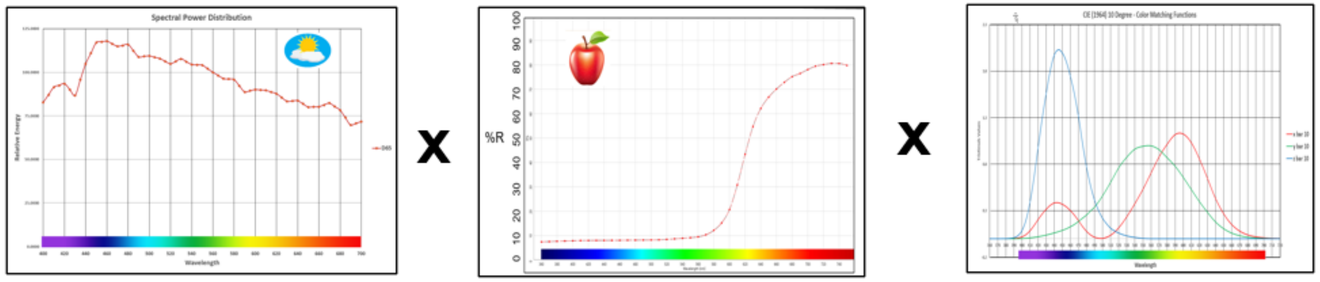


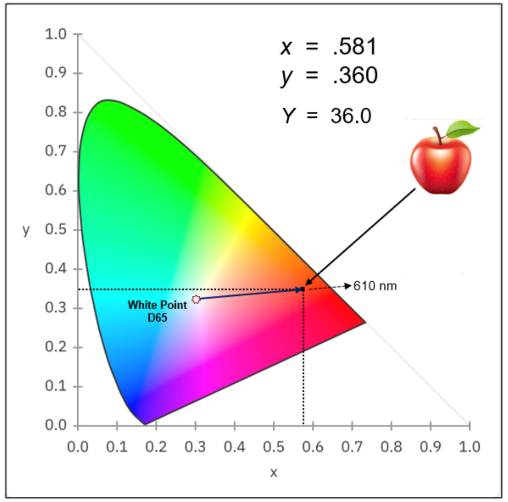
Tristimulus Values

Chromaticity Coordinates

Colorimetric Description

Standard Observer

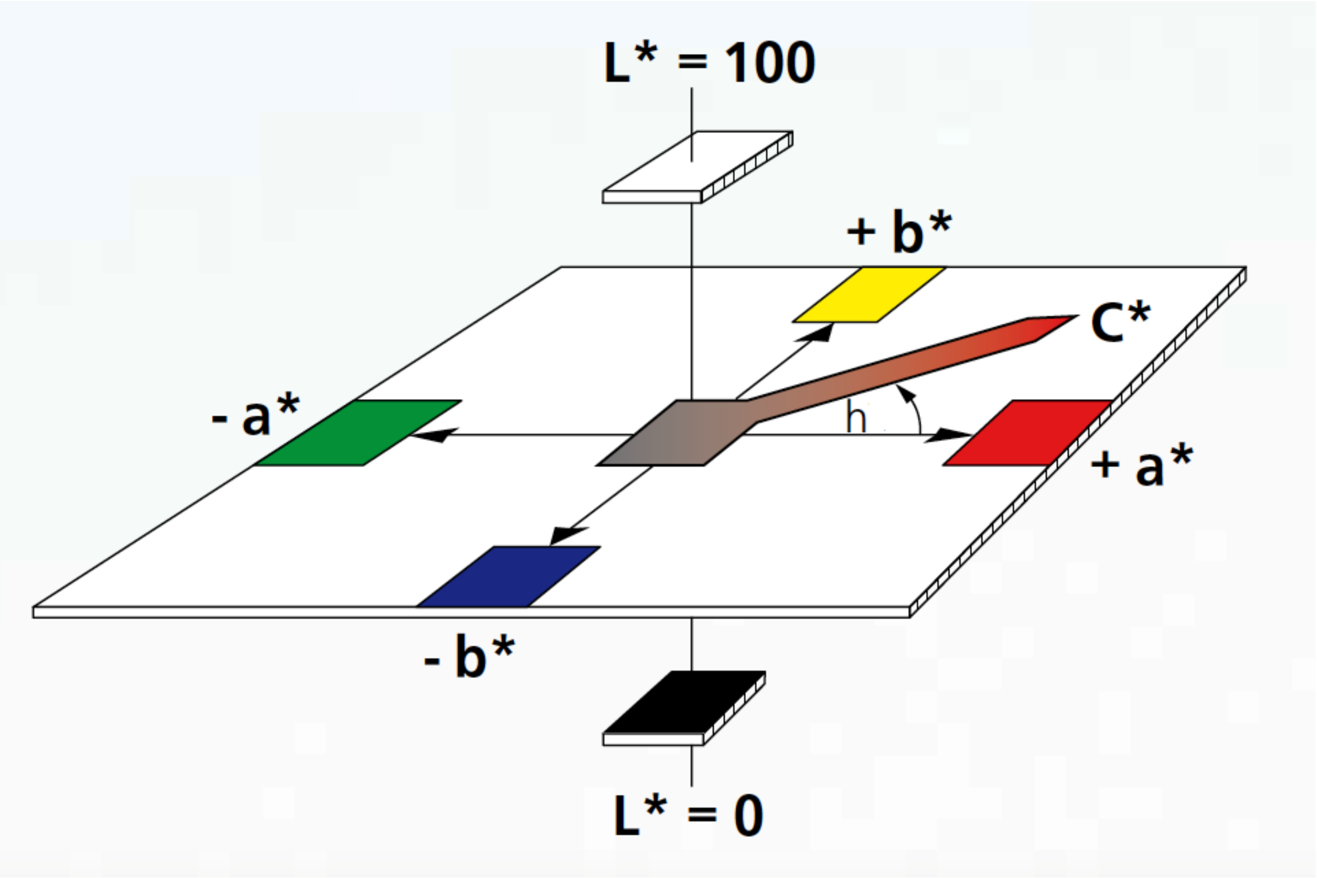




Next session:

Color Coordinates

- CIELAB
- Polar/Rectangular Coordinates
- Lab vs LCh
- Color Difference – DE*
- CMC
- CIE2000



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Some useful reading material:

Do You Know How Humans See Color?

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