Fundamentals of Color and Appearance

Module 6

Light, Illuminant and Observer

Color Science Educational Series

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A light source is any physical source of visible light, such as natural daylight, incandescent bulbs and fluorescent lamps

Natural Daylight

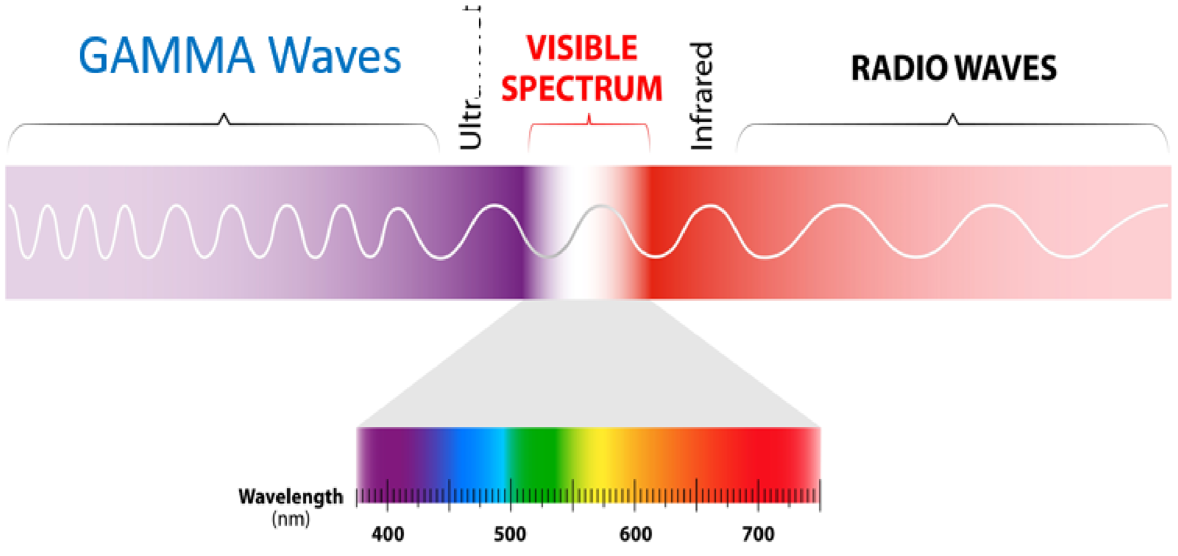
Incandescent

Fluorescent

In previous modules, we learned that visible light makes up only a small slice of the vast electromagnetic spectrum, which includes everything from gamma rays to radio waves.

The wavelengths of light that impact how we see the color of objects span from approximately three hundred sixty, to seven hundred eighty nanometers.

ELECTROMAGNETIC SPECTRUM



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The International Commission on Illumination, or CIE, is the global authority responsible for defining standard illuminants, color spaces, and colorimetric systems.

Their work provides the scientific foundation for virtually all color measurement and lighting standards used across industries, ensuring that color can be measured, communicated, and reproduced with accuracy and consistency worldwide.

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

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A key contribution to color science are **CIE Standard Illuminants**, theoretical light sources defined and characterized by the CIE in a table of numbers.

These mathematical representations of light define the chromaticity, perceived color, and correlated color temperatures in degrees Kelvin, of various light sources.

Name	CIE 1931 2°		CIE 1964 10°		CCT (K)	Color	Note
	$x_{2°}$	$y_{2°}$	$x_{10°}$	$y_{10°}$			
A	0.44757	0.40745	0.45117	0.40594	2856		incandescent / tungsten
B	0.34842	0.35161	0.34980	0.35270	4874		obsolete, direct sunlight at noon
C	0.31006	0.31616	0.31039	0.31905	6774		obsolete, average / North sky daylight / NTSC 1953[28], PAL-M[29]
D50	0.34567	0.35850	0.34773	0.35952	5003		horizon light, ICC profile PCS
D55	0.33242	0.34743	0.33411	0.34877	5503		mid-morning / mid-afternoon daylight
D65	0.31271	0.32902	0.31382	0.33100	6504		noon daylight: television, sRGB color space
D75	0.29902	0.31485	0.29968	0.31740	7504		North sky daylight

For example, **Illuminant D65** represents average noon daylight with a correlated color temperature of approximately 6500 Kelvin, producing a cool, bluish-white light commonly used as a reference in color matching and quality control.

Name	CIE 1931 2°		CIE 1964 10°		CCT (K)	Color	Note
	$x_{2°}$	$y_{2°}$	$x_{10°}$	$y_{10°}$			
D65	0.31271	0.32902	0.31382	0.33100	6504		noon daylight: television, sRGB color space

Illuminant 'A' represents incandescent lighting, a common light source used in home and bedroom lighting, with a correlated color temperature of 2856 Kelvin.

Name	CIE 1931 2°		CIE 1964 10°		CCT (K)	Color	Note
	$x_{2°}$	$y_{2°}$	$x_{10°}$	$y_{10°}$			
A	0.44757	0.40745	0.45117	0.40594	2856		incandescent / tungsten

And **'F' series illuminants** represent variations of fluorescent lighting commonly used in office and department store settings.

Name	CIE 1931 2°		CIE 1964 10°		CCT (K)	Color	Note
	$x_{2°}$	$y_{2°}$	$x_{10°}$	$y_{10°}$			
F1	0.31310	0.33727	0.31811	0.33559	6430		Daylight Fluorescent
F2	0.37208	0.37529	0.37925	0.36733	4230		Cool White Fluorescent
F3	0.40910	0.39430	0.41761	0.38324	3450		White Fluorescent

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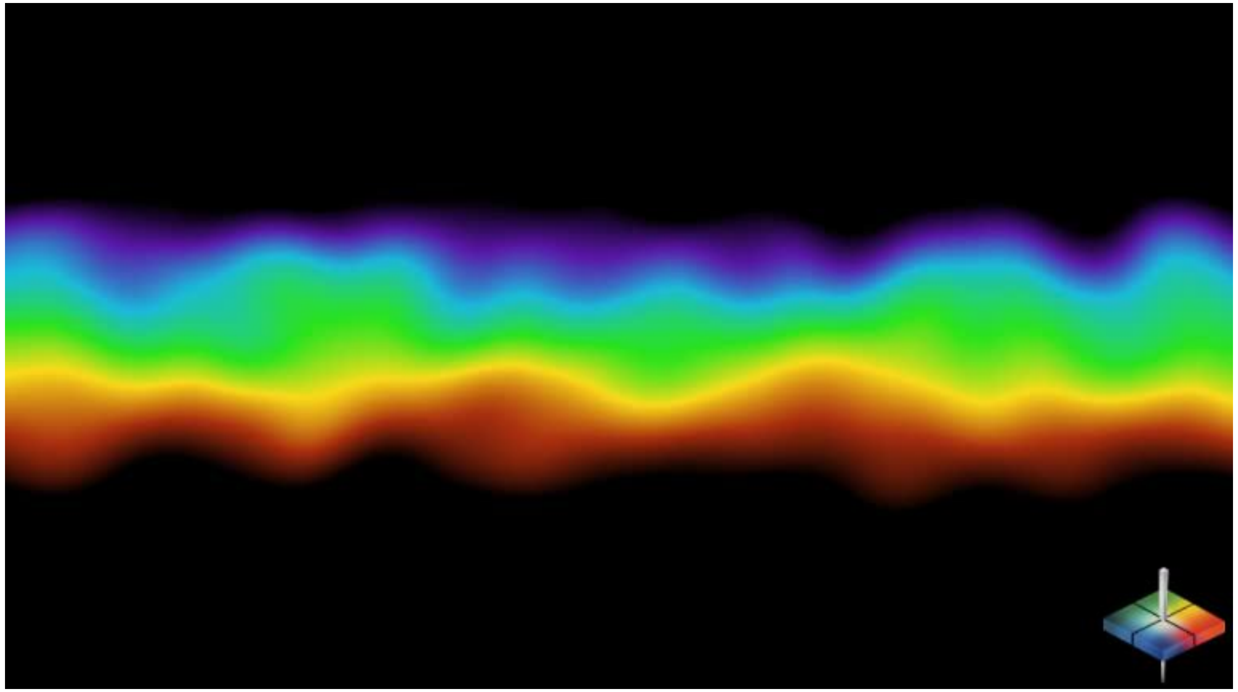
These examples we just looked at represent just a few of the many standard illuminants developed by the CIE.

These CIE standard illuminants are critically important in instrumental color measurement because they provide consistent, standardized representations of light sources under which color measurements are made and compared, ensuring that color measurements are repeatable, objective, and comparable across different instruments, locations, and times.

Name	CIE 1931		CIE 1964		CCT (K)	Hue	Note
	x2	y2	x10	y10			
A	0.44757	0.40745	0.45117	0.40594	2856		Incandescent / Tungsten
B	0.34842	0.35161	0.3498	0.3527	4874		{obsolete} Direct sunlight at noon
C	0.31006	0.31616	0.31039	0.31905	6774		{obsolete} Average / North sky Daylight
D50	0.34567	0.35850	0.34773	0.35952	5003		Horizon Light. ICC profile PCS
D55	0.33242	0.34743	0.33411	0.34877	5503		Mid-morning / Mid-afternoon Daylight
D65	0.31271	0.32902	0.31382	0.33100	6504		Noon Daylight: Television, sRGB color space
D75	0.29902	0.31485	0.29968	0.31740	7504		North sky Daylight
E	1/3	1/3	1/3	1/3	5454		Equal energy
F1	0.31310	0.33727	0.31811	0.33559	6430		Daylight Fluorescent
F2	0.37208	0.37529	0.37925	0.36733	4230		Cool White Fluorescent
F3	0.40910	0.39430	0.41761	0.38324	3450		White Fluorescent
F4	0.44018	0.40329	0.44920	0.39074	2940		Warm White Fluorescent
F5	0.31379	0.34531	0.31975	0.34246	6350		Daylight Fluorescent
F6	0.37790	0.38835	0.38660	0.37847	4150		Lite White Fluorescent
F7	0.31292	0.32933	0.31569	0.32960	6500		D65 simulator, Daylight simulator
F8	0.34588	0.35875	0.34902	0.35939	5000		D50 simulator, Sylvania F40 Design 50
F9	0.37417	0.37281	0.37829	0.37045	4150		Cool White Deluxe Fluorescent
F10	0.34609	0.35986	0.35090	0.35444	5000		Philips TL85, Ultralume 50
F11	0.38052	0.37713	0.38541	0.37123	4000		Philips TL84, Ultralume 40
F12	0.43695	0.40441	0.44256	0.39717	3000		Philips TL83, Ultralume 30

Now let's look at **Spectral Distributions**, or **SPDs**, of light sources.



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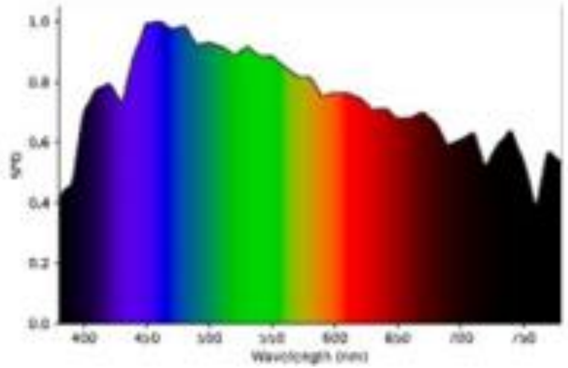
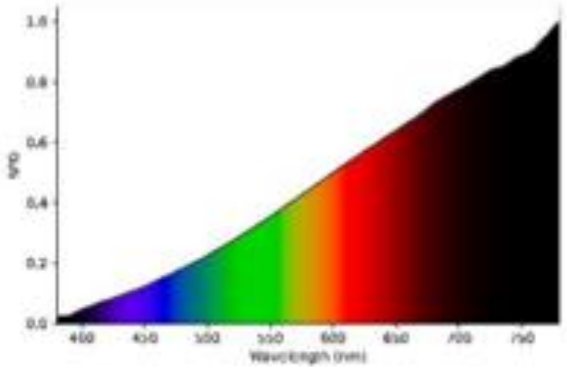
A Spectral Power Distribution curve is a graphical representation that plots the relative energy of a light source at each wavelength across the visible spectrum.

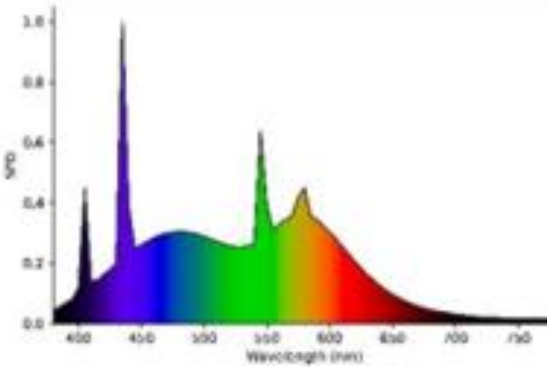
Every illuminant has a unique Spectral Power Distribution, which determines how it interacts with objects and thus directly affects how colors appear under that lighting.



Illuminant D_{65} (Noon Daylight)



Illuminant A (Incandescent)

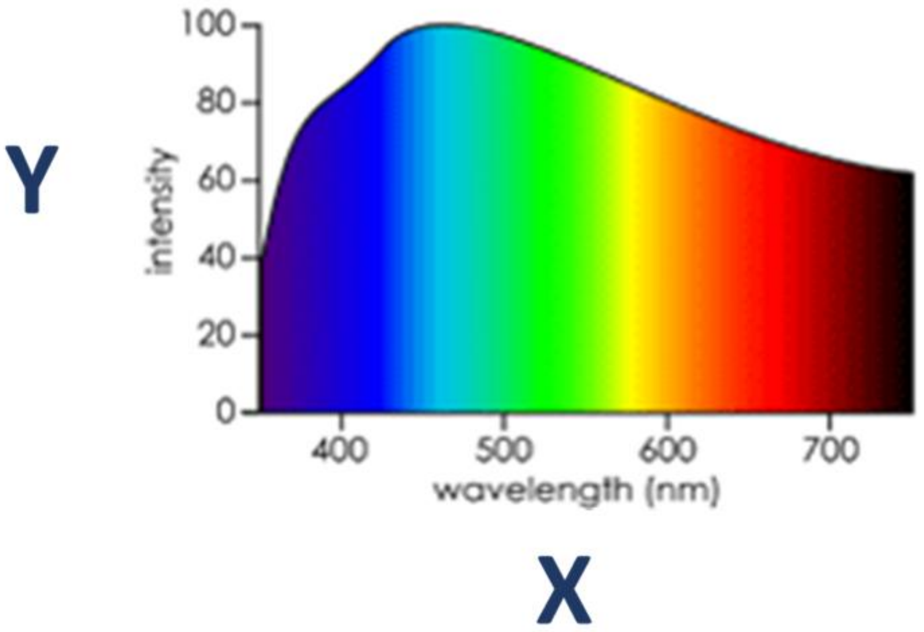


Illuminant F2 (Fluorescent)

Understanding a Spectral Distribution Curve

X axis: Wavelengths spanning the visible spectrum.

Y axis: Relative energy (intensity) at each wavelengths across the visible spectrum.



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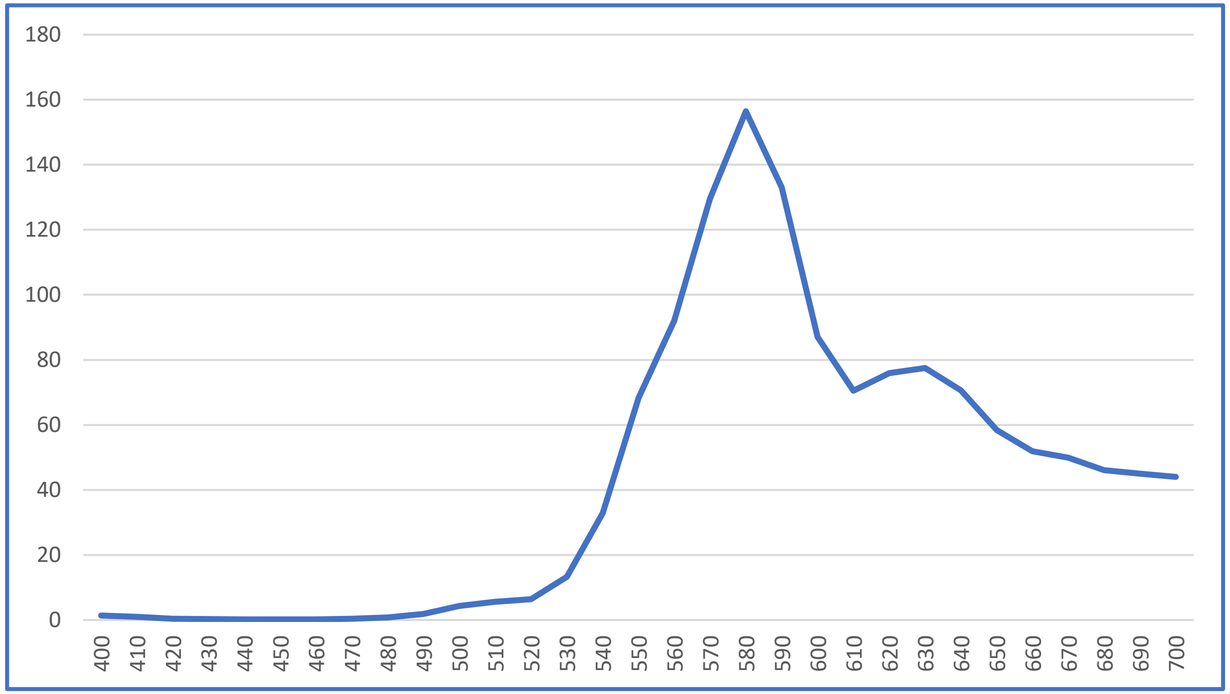
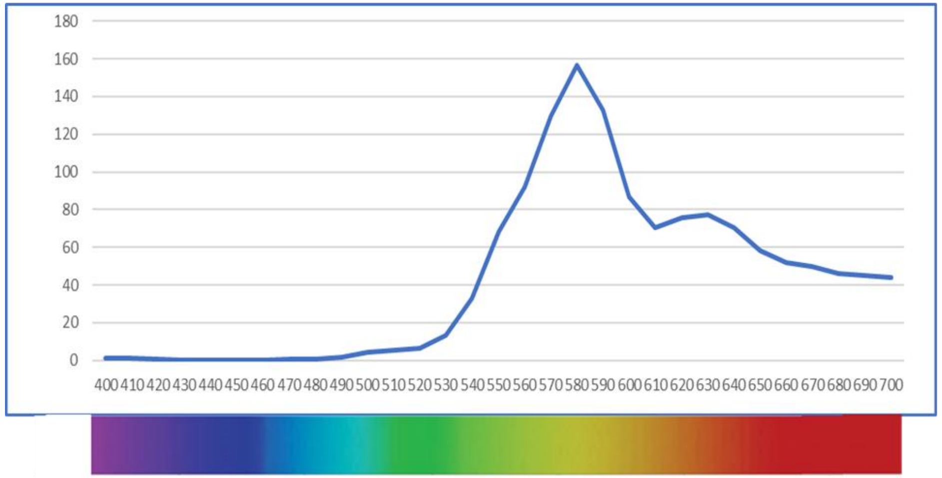
Understanding a Spectral Distribution Curve



What color is this?

Understanding a Spectral Distribution Curve



Because the light energy is highest in the yellow/red range of visible light, this spectral distribution is the fingerprint for this yellow lemon.

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Light, Illuminant and Observer

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	Daylight	Incandescent	Fluorescent

Light Source

Illuminant

CIE Illuminant D_{65}

CIE 1931 2°		CIE 1964 10°		CCT (K)	Color
$x_{2°}$	$y_{2°}$	$x_{10°}$	$y_{10°}$		
0.31006	0.31616	0.31039	0.31905	6774	

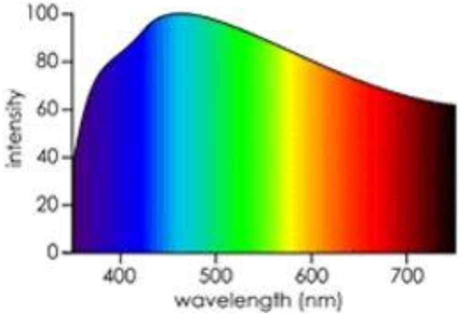
CIE Illuminant A

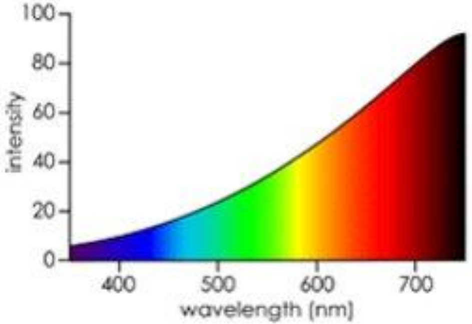
CIE 1931 2°		CIE 1964 10°		CCT (K)	Color
$x_{2°}$	$y_{2°}$	$x_{10°}$	$y_{10°}$		
0.44757	0.40745	0.45117	0.40594	2856	

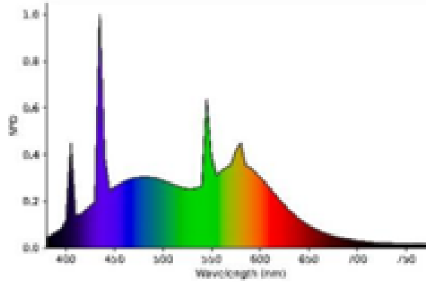
CIE Illuminant F2

CIE 1931 2°		CIE 1964 10°		CCT (K)	Color
$x_{2°}$	$y_{2°}$	$x_{10°}$	$y_{10°}$		
0.37208	0.37529	0.37925	0.36733	4230	

Spectral Distribution Curve (SPD)







Fluorescent

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Light Source

Daylight

Incandescent

Fluorescent

Illuminant

CIE Illuminant D_{65}

CIE 1931 2°		CIE 1964 10°		CCT (K)	Color
$x_{2°}$	$y_{2°}$	$x_{10°}$	$y_{10°}$		
0.31006	0.31616	0.31039	0.31905	6774	

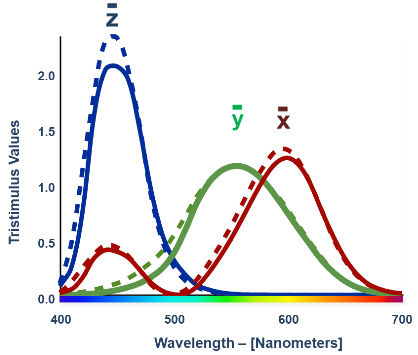
CIE Illuminant A

CIE 1931 2°		CIE 1964 10°		CCT (K)	Color
$x_{2°}$	$y_{2°}$	$x_{10°}$	$y_{10°}$		
0.44757	0.40745	0.45117	0.40594	2856	

CIE Illuminant F2

CIE 1931 2°		CIE 1964 10°		CCT (K)	Color
$x_{2°}$	$y_{2°}$	$x_{10°}$	$y_{10°}$		
0.37208	0.37529	0.37925	0.36733	4230	

Observer



CIE 2° Standard Observer

CIE 10° Standard Observer

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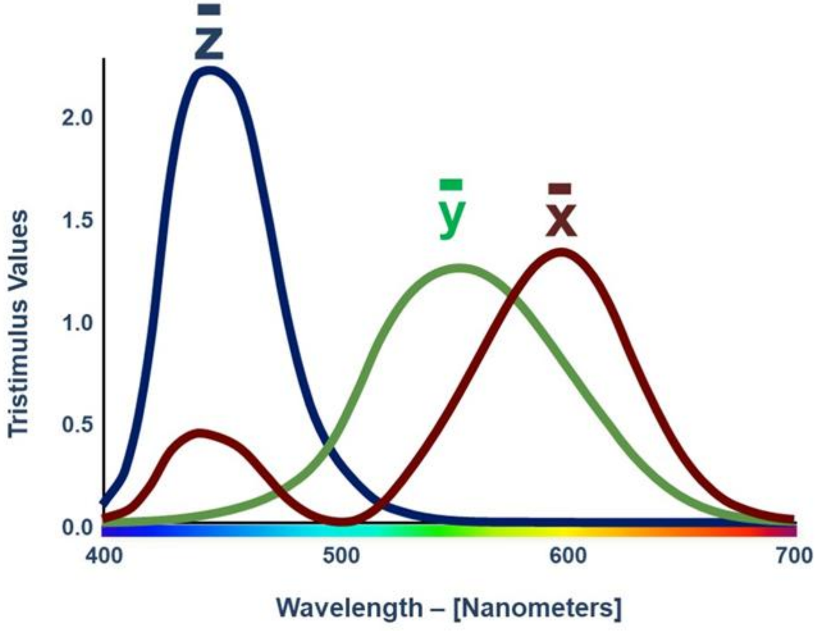
XYZ Tristimulus Values

Now let's look at **XYZ tristimulus values**, a representation of how light stimulates our photo receptors and allow us to perceive color.

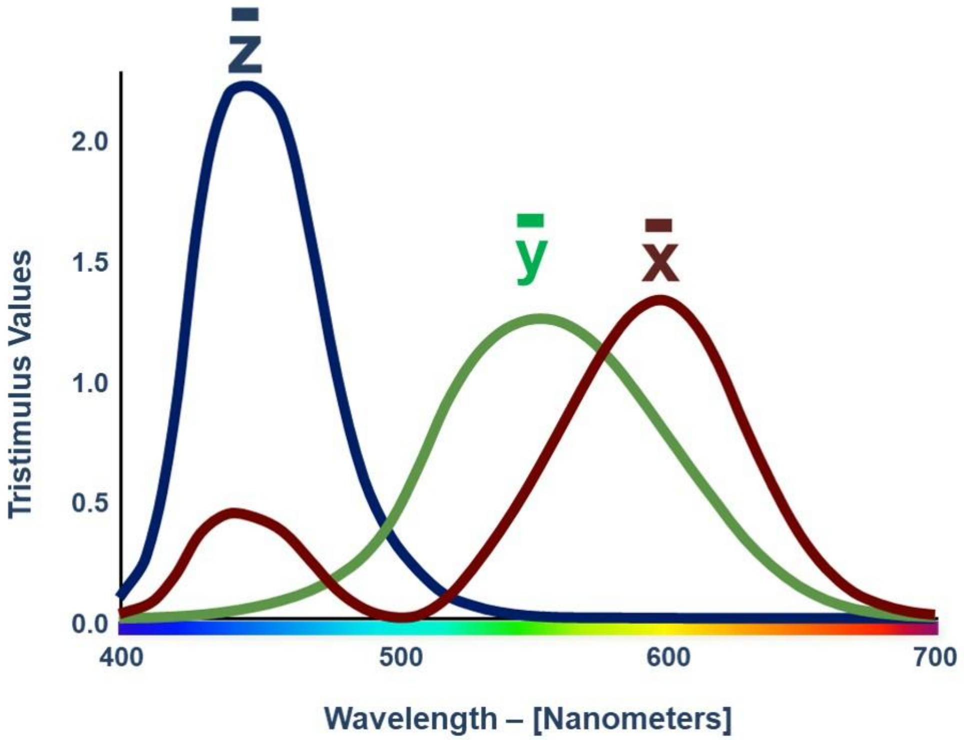
These values are the basis for the development of all color scales and color indices used in color measurement to evaluate and communicate color.



Tristimulus values are three values (X, Y, Z) that together are used to describe a color.

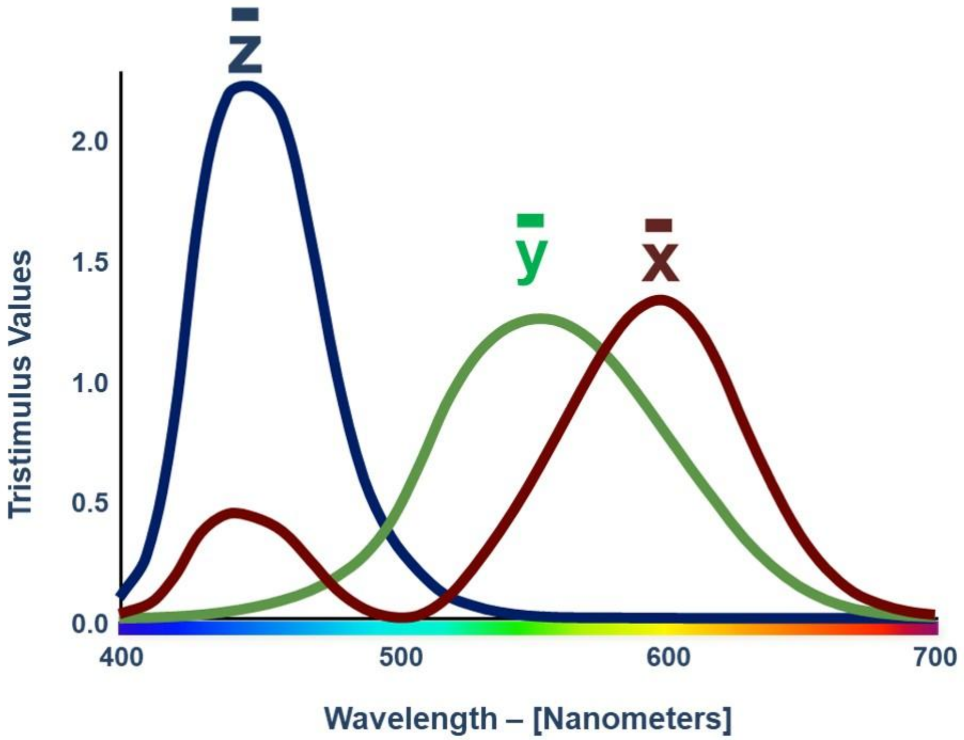
Tristimulus values measure the light intensity of the primary color values in a sample.

CIE 1931 XYZ was the first attempt to produce a color space based on measurements of human color perception and is the basis for almost all other color spaces.



These values are calculated based on three key inputs:

- The object's reflectance or transmittance spectrum.
- The spectral power distribution of the illuminant.
- The CIE Standard Observer function, which models the average human eye's sensitivity to different wavelengths.



We will discuss Standard Observer Functions next.

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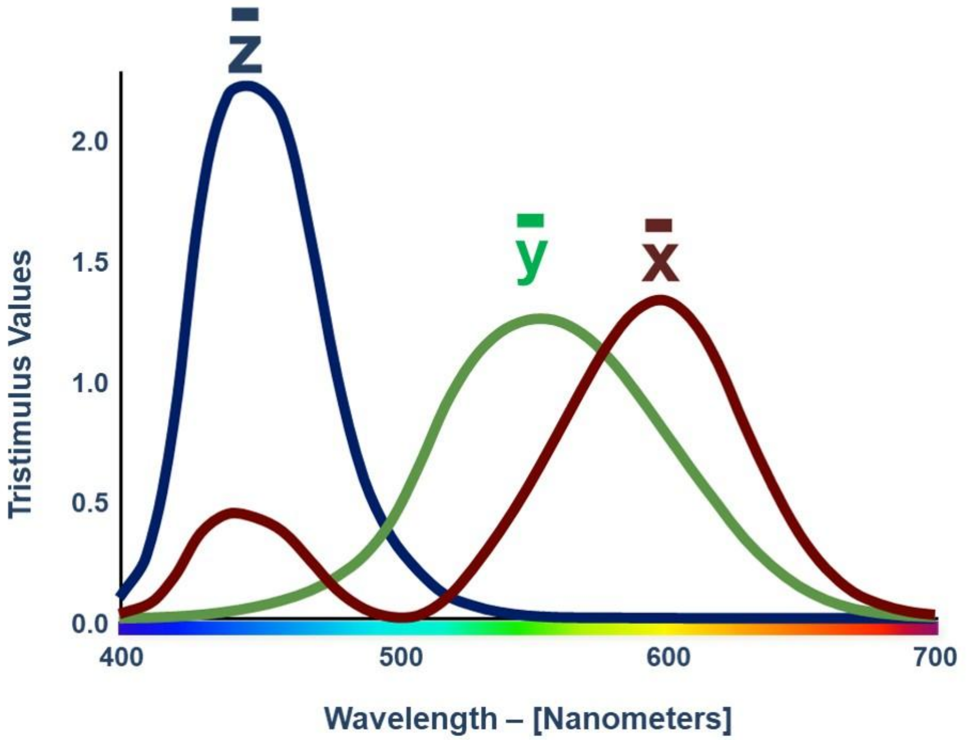
Light, Illuminant and Observer

CIE X,Y, Z tristimulus color values are obtained by multiplying the illuminant, the reflectance or transmittance of the object, and the standard observer functions.

The product is then summed for all wavelengths in the visible spectrum to give the resulting X, Y, Z tristimulus values.



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Because not everyone sees color the same way, the CIE introduced the **Standard Colorimetric Observer**, a mathematical model that represents the average human visual response to color.

Light, Illuminant and Observer

Due to the distribution of cones in the eye, the tristimulus values depend on the observer's **field of view.**

To eliminate this variable, the CIE defined a color-mapping function called the **standard (colorimetric) observer**, to represent an average human's chromatic response inside the fovea.

The **standard observer** is a set of three-color matching functions that represents the visual system of a "**standard**" person with "**color normal**" vision for a specified field of view.

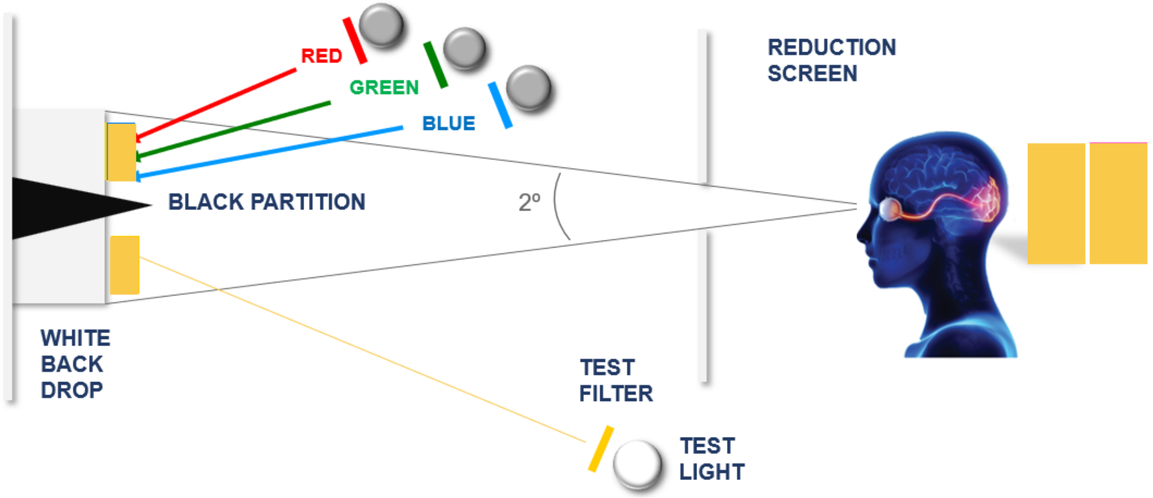
It is a mathematical function that describes the average human eye's response to colors in the visible spectrum with a **2-degree field of view and a 10-degree field of view.**

It is based on experiments where observers were asked to match monochromatic wavelengths of light with mixtures of three primary colors **(red, green and blue).**

In 1931, experiments were conducted where human subjects visually matched a test light using a combination of three different colored lights, red, green and blue, within a 2-degree field of view.

This experiment focused light on the area of the retina corresponding to the central foveal region, where color sensitivity is the highest.

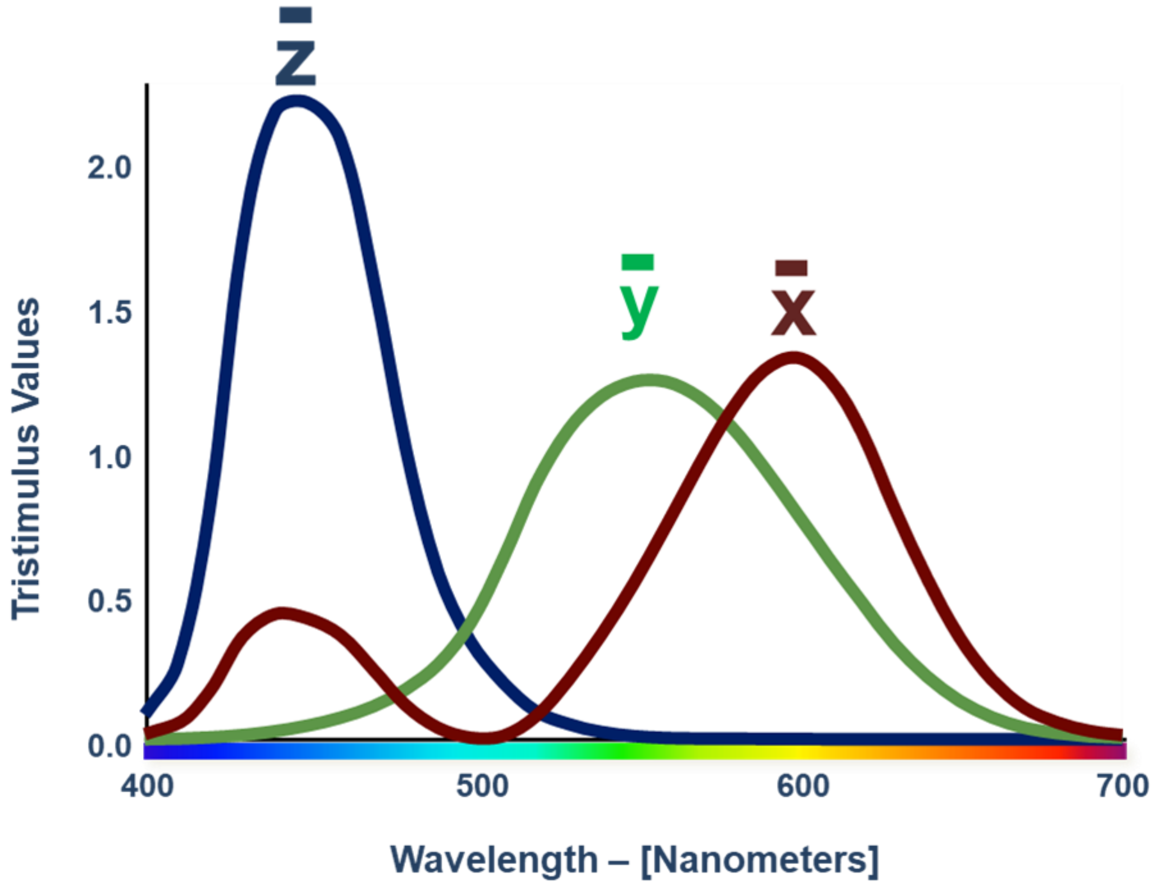
Determination of Standard Colorimetric Observer



The results defined the average human's color perception for this small visual field and led to the creation of the **1931 two-degree observer** color matching functions.

These functions quantify the red, green and blue cone sensitivity of the average human observer.

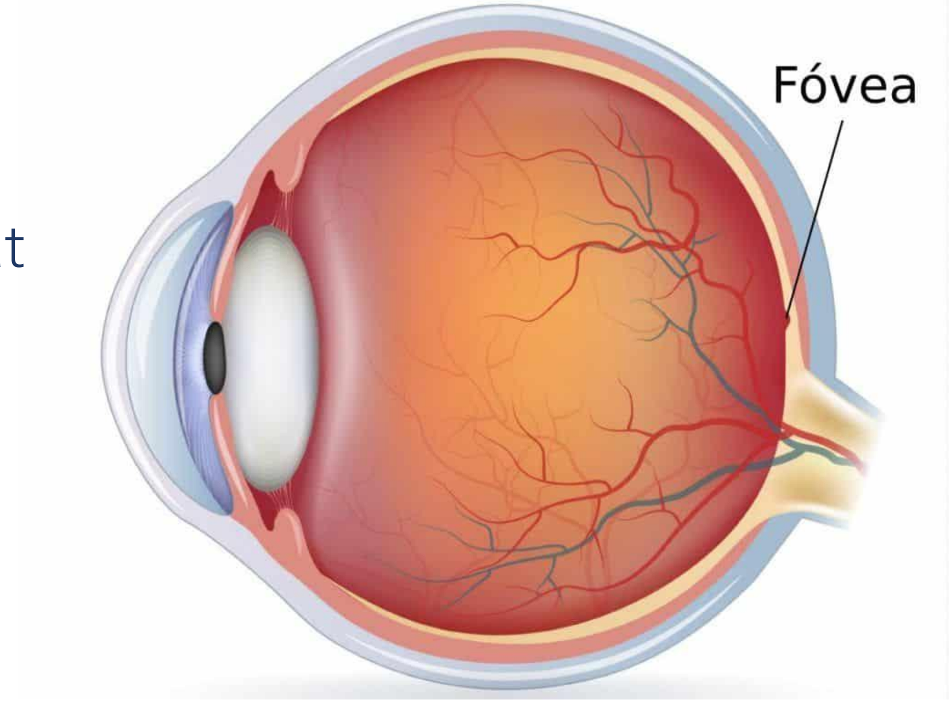
2° Standard Observer



2° and 10° Standard Observer

When the 1931 two-degree Standard Observer experiments were conducted, it was believed that cone cells, responsible for color vision, were concentrated primarily in the fovea.

Later studies showed broader cone distribution.



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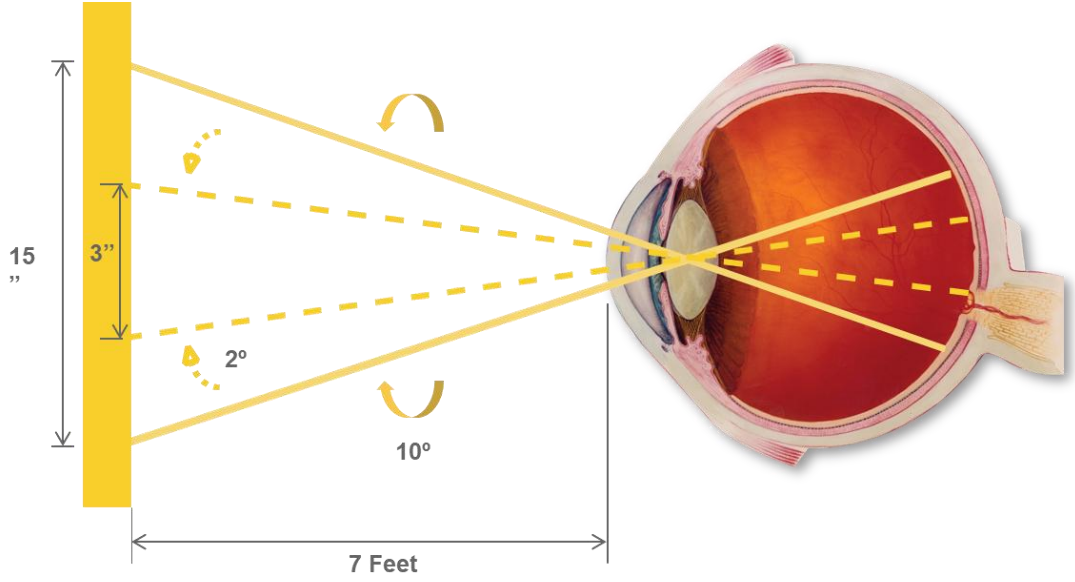
This led to a shift from the **CIE 1931 two-degree Standard Observer** to the **CIE 1964 ten-degree Standard Observer**, driven by the need to account for a larger field of view in practical color evaluations.

While the two-degree observer models the response of the human eye's central vision, the ten-degree observer includes a broader area of the retina, incorporating more peripheral vision where cones still contribute to color perception.



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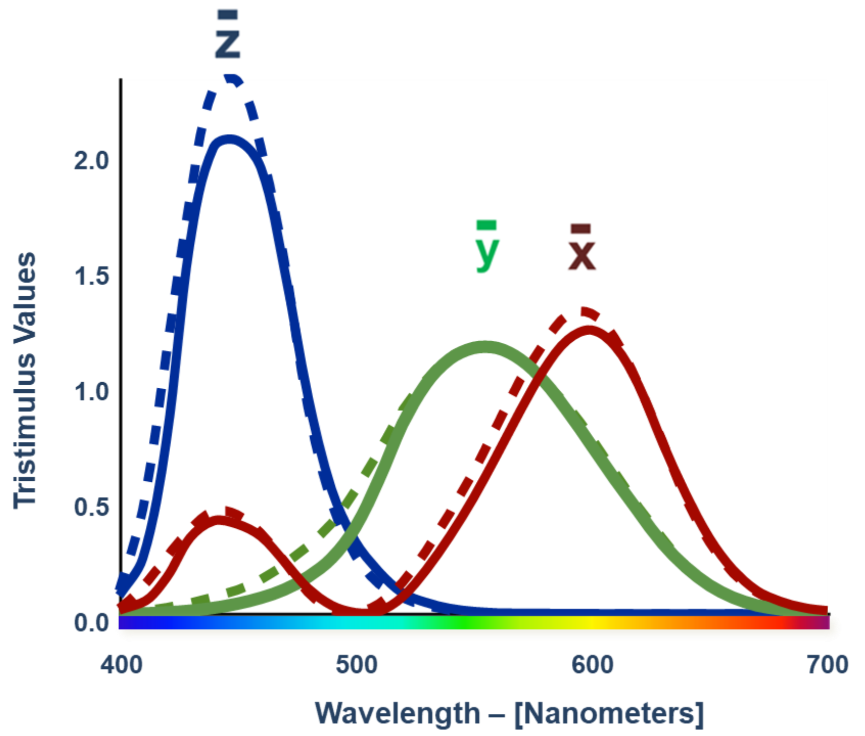
This image compares the CIE 2-degree Standard Observer XYZ functions, represented by the solid lines, and the expanded 10-degree Standard Observer XYZ functions, represented by the dashed lines.

Of the two observers, the CIE recommends the 10° Standard Observer. It best correlates with average visual assessments made with large fields of view, typical of most commercial applications, and considered to be more accurate than the 2° standard observer.

2° versus 10° CIE Standard Observer



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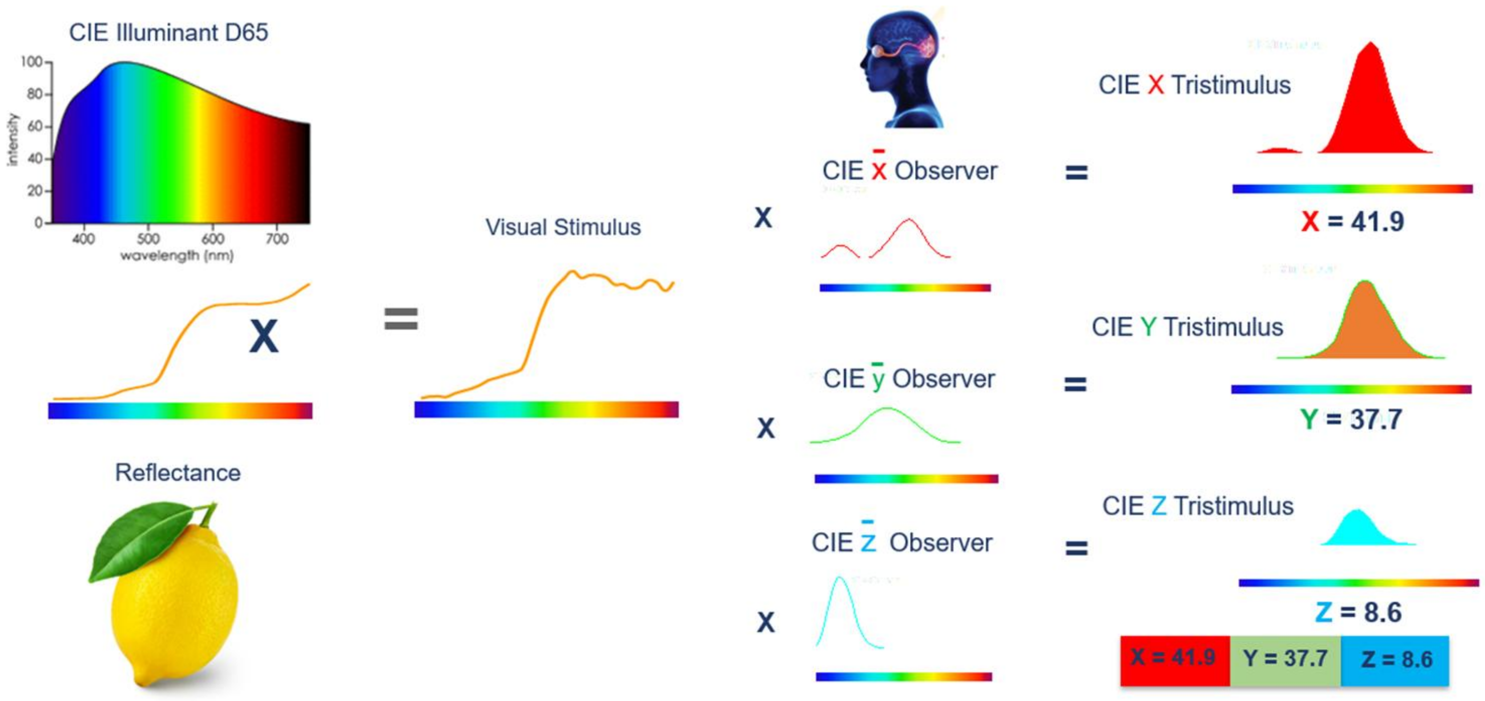
Bringing this section to a close, XYZ is calculated by multiplying the illuminant spectral distribution by the sample's reflectance and the standard observer function. The result is summed across the visible spectrum.



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These values can then be converted into color spaces like CIE L*, a*, b*, Hunter L,a,b, and other industry recognized color scales and color indices.

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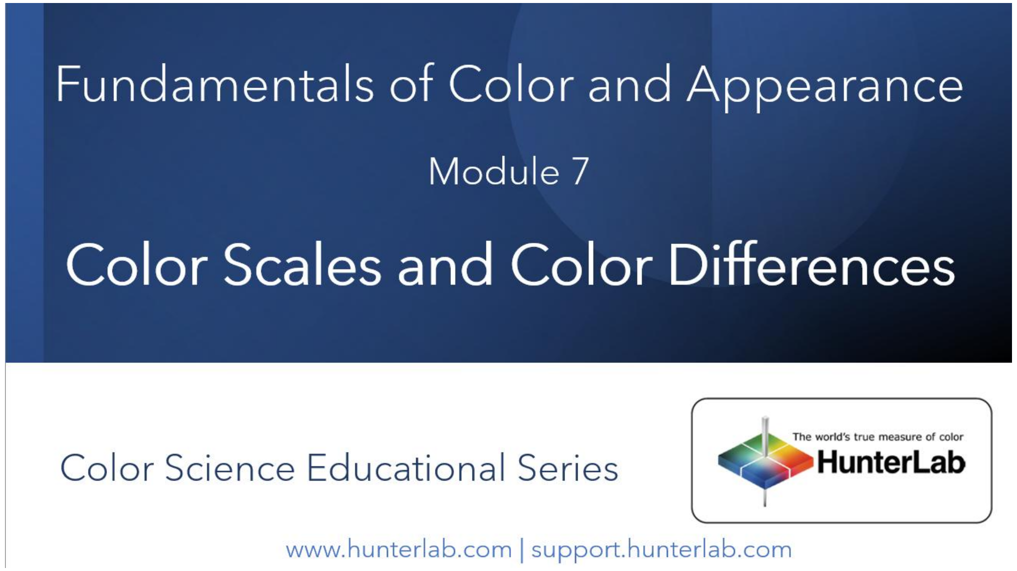
Thank you for joining us on this journey through color science.

Be sure to watch Module 7, **Color Scales and Color Difference**, where we will discuss The Opponent Color Theory, Symmetric and asymmetric color differences and how they are calculated, and how to set minimum perceptible, and maximum acceptable, color tolerances for your products.

And be sure to visit **hunterlab.com** to learn more about how our solutions can help you achieve color confidence, every time, or to schedule a consultation with one of our color experts.



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