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Color Theory – Part 1

Color and Appearance

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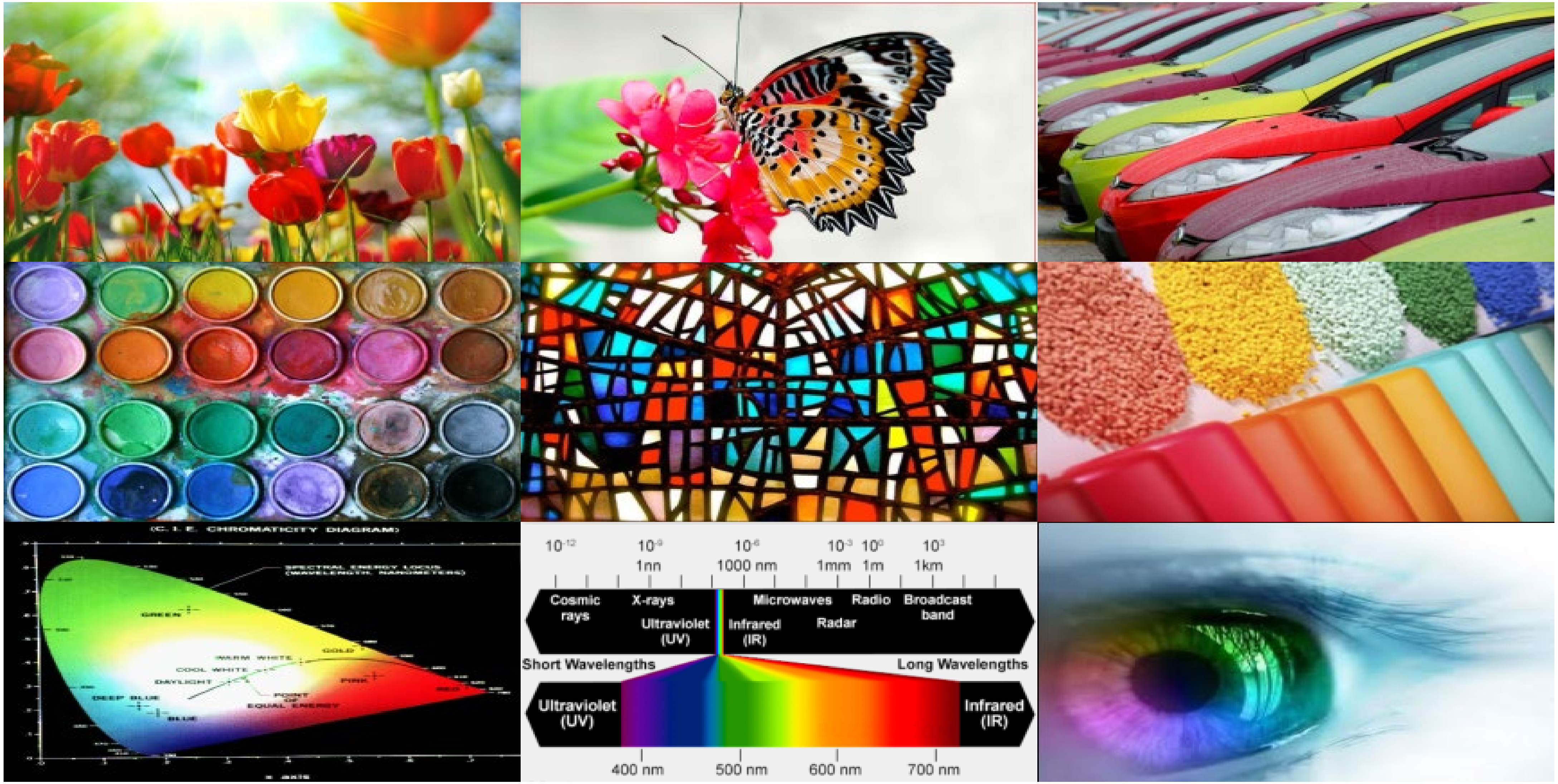


What is Color?

Color is a **perception.**

Color perception happens in the brain.

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

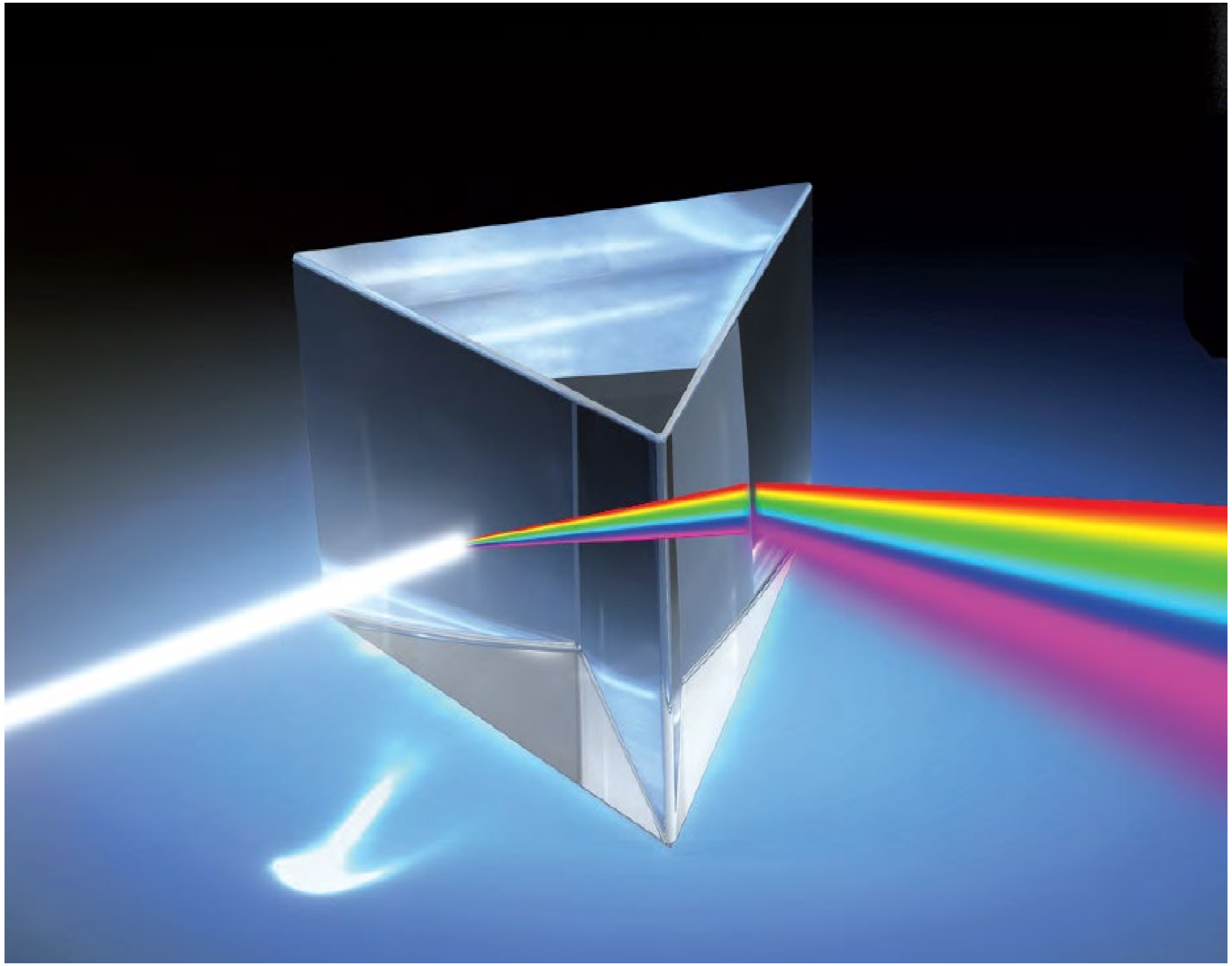
Color perception depends on 3 things:

Light Source

Object

Observer

Light – The Source of All Color



What is Light?

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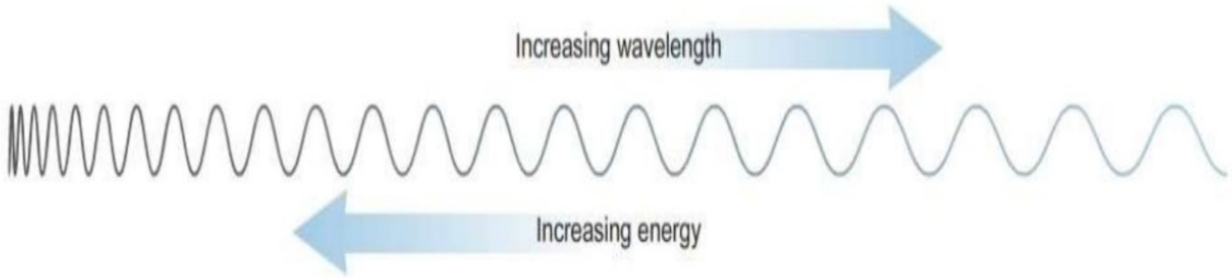
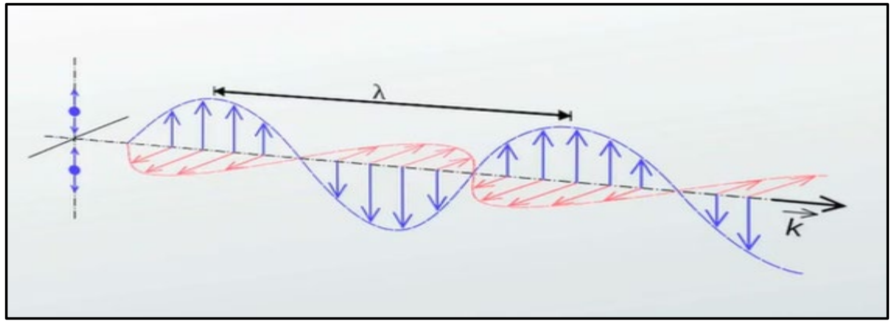
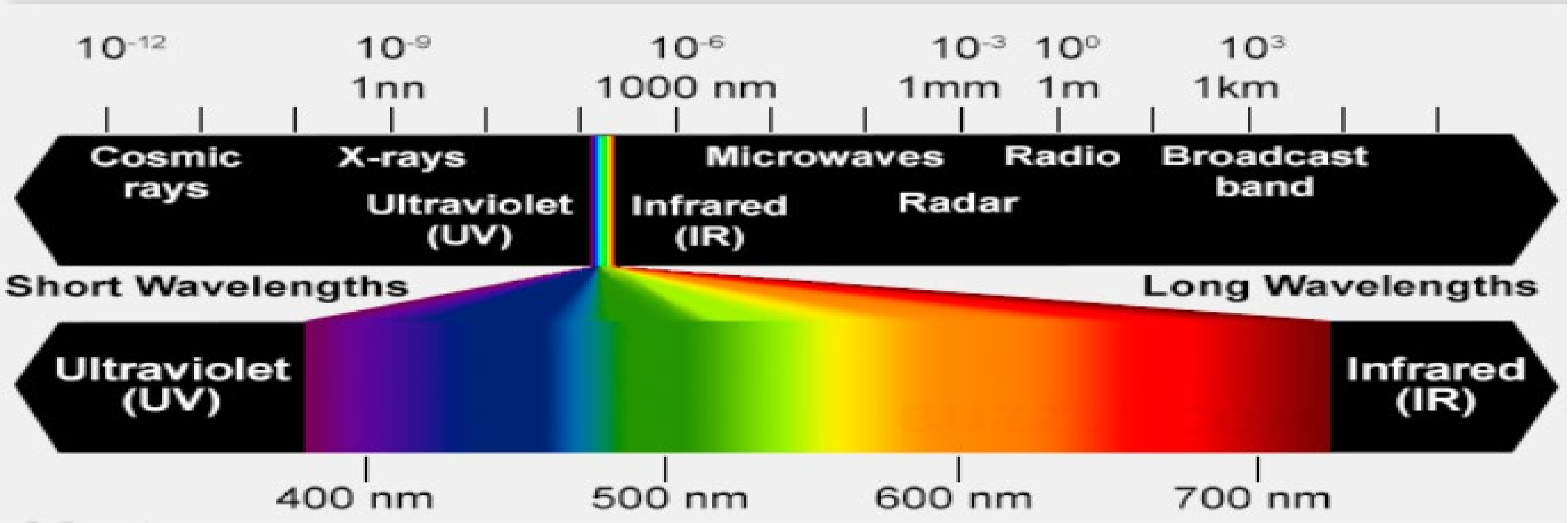
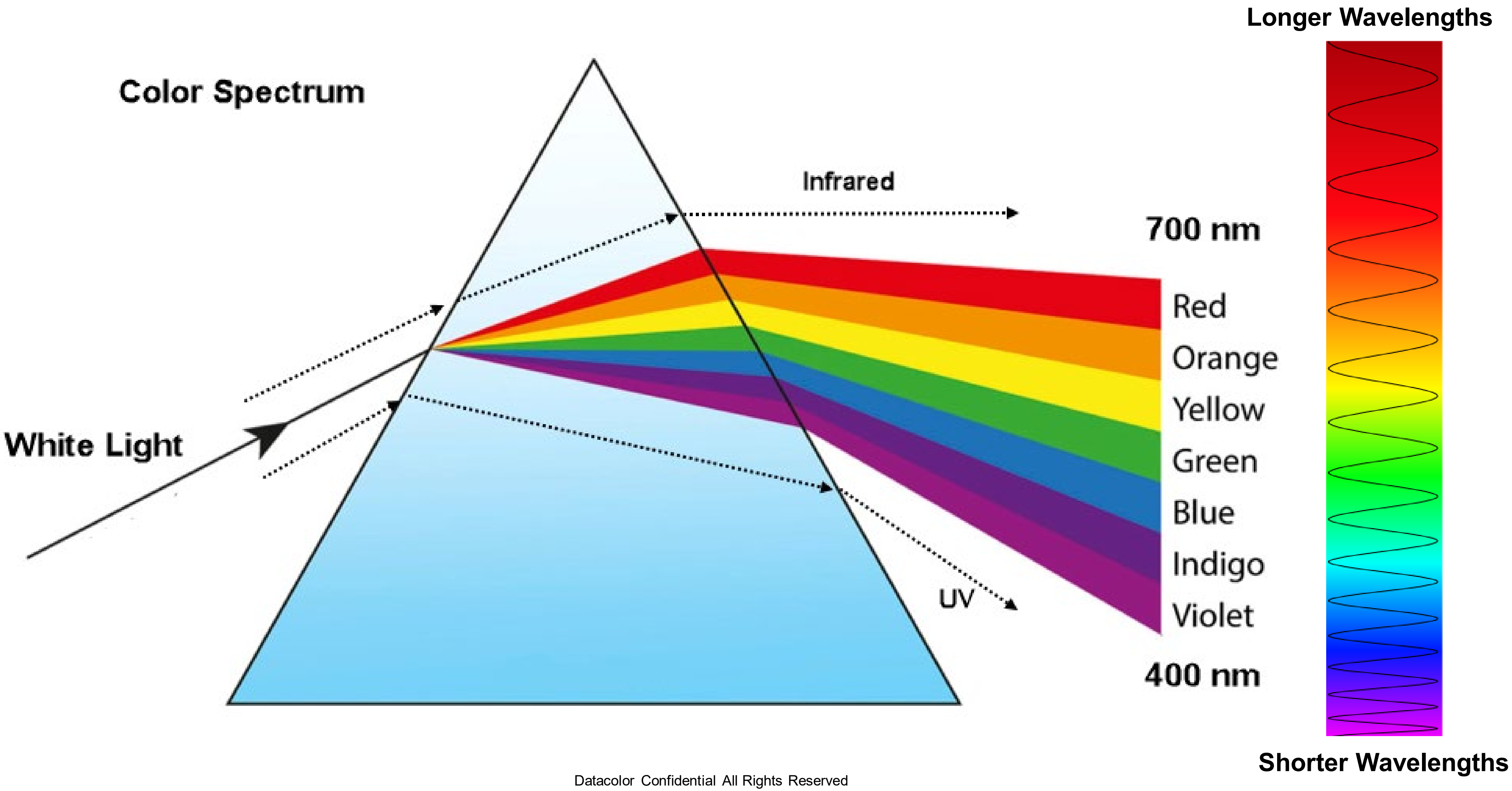
"Light" is a special, narrow range of electromagnetic energy.







Visible Spectrum



Light Sources – Spectral Power Distribution

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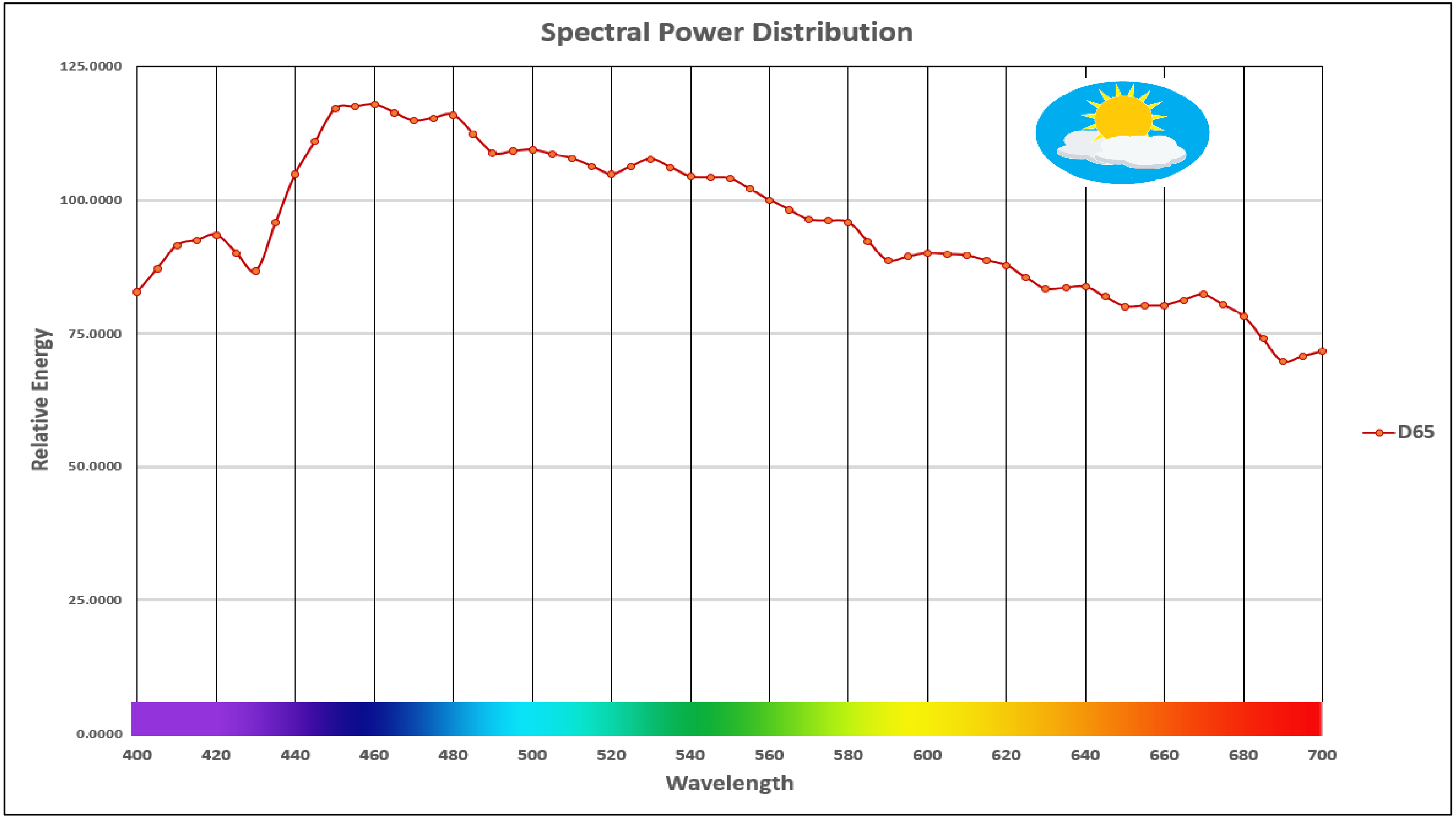
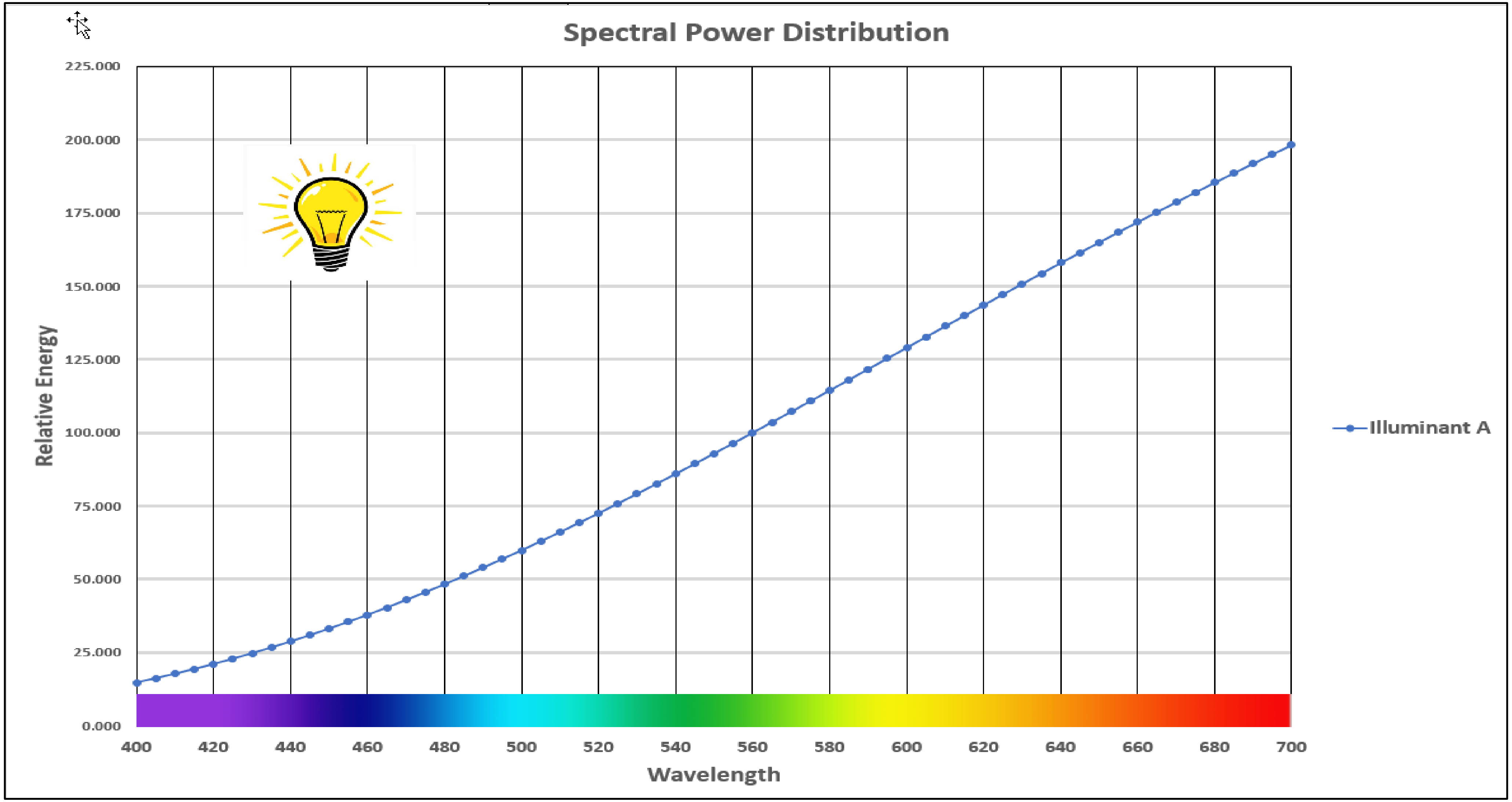


Light Sources – Incandescent



Light Sources - Fluorescent

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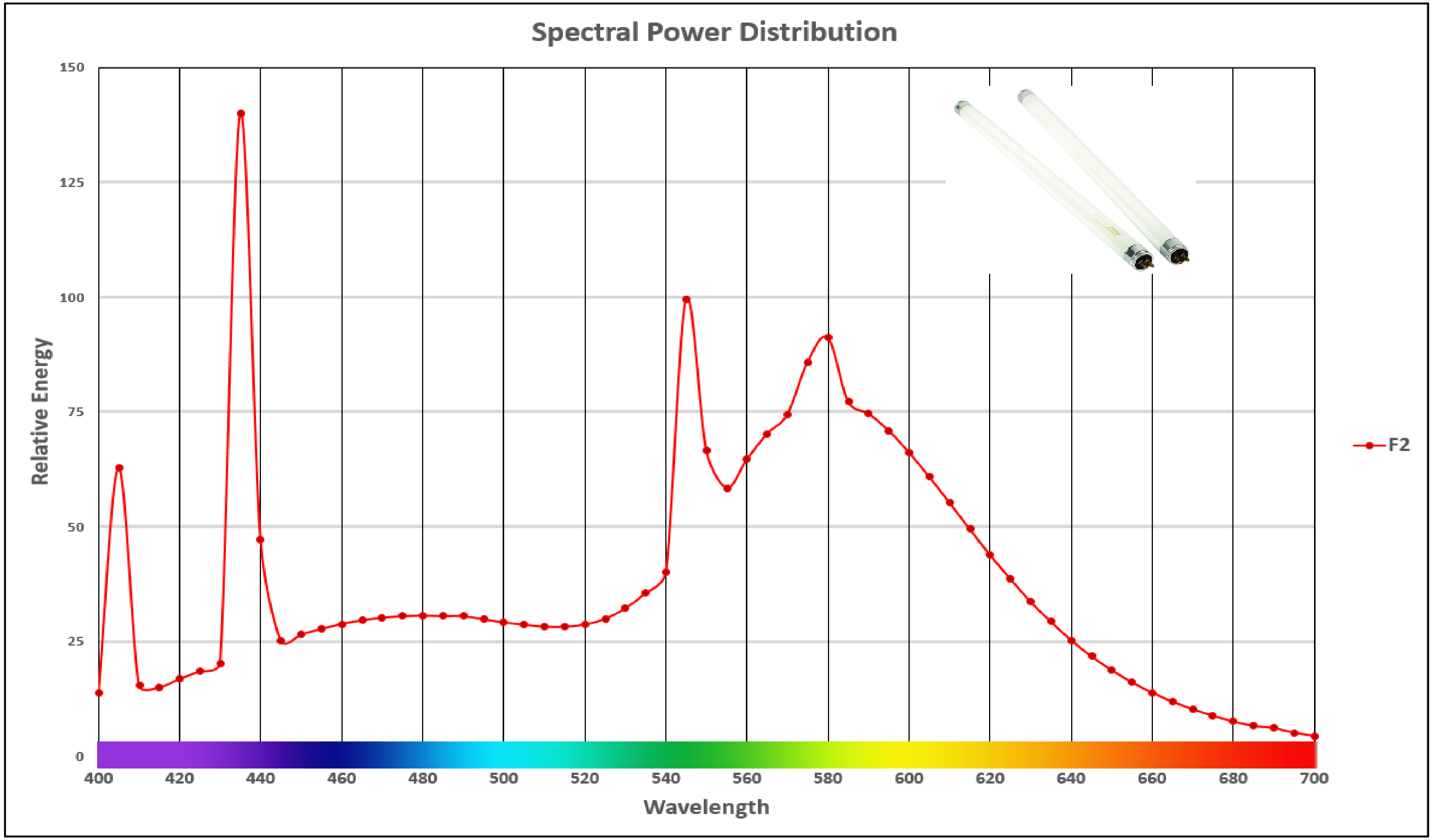

Light Sources - LED

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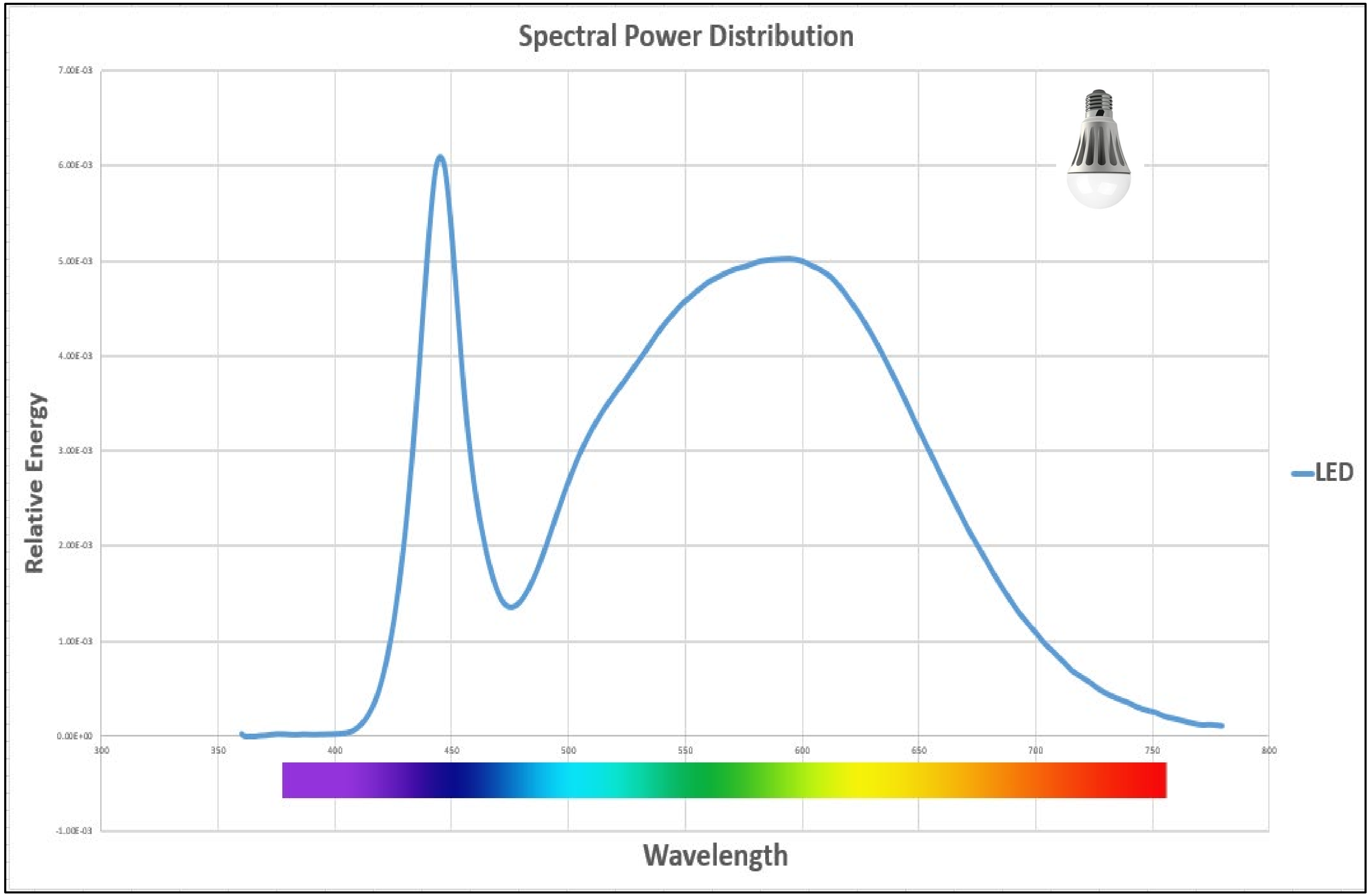

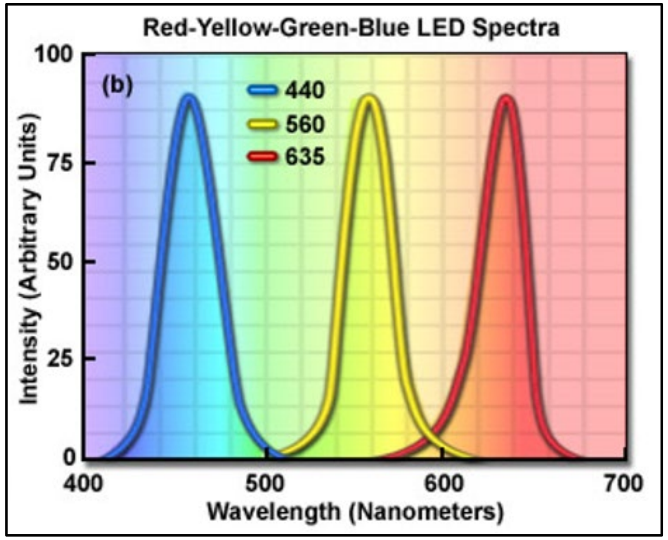

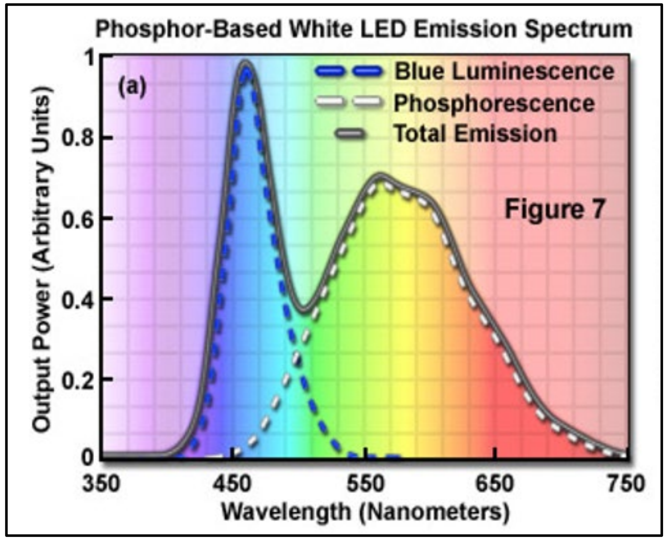

Light Sources - Comparison

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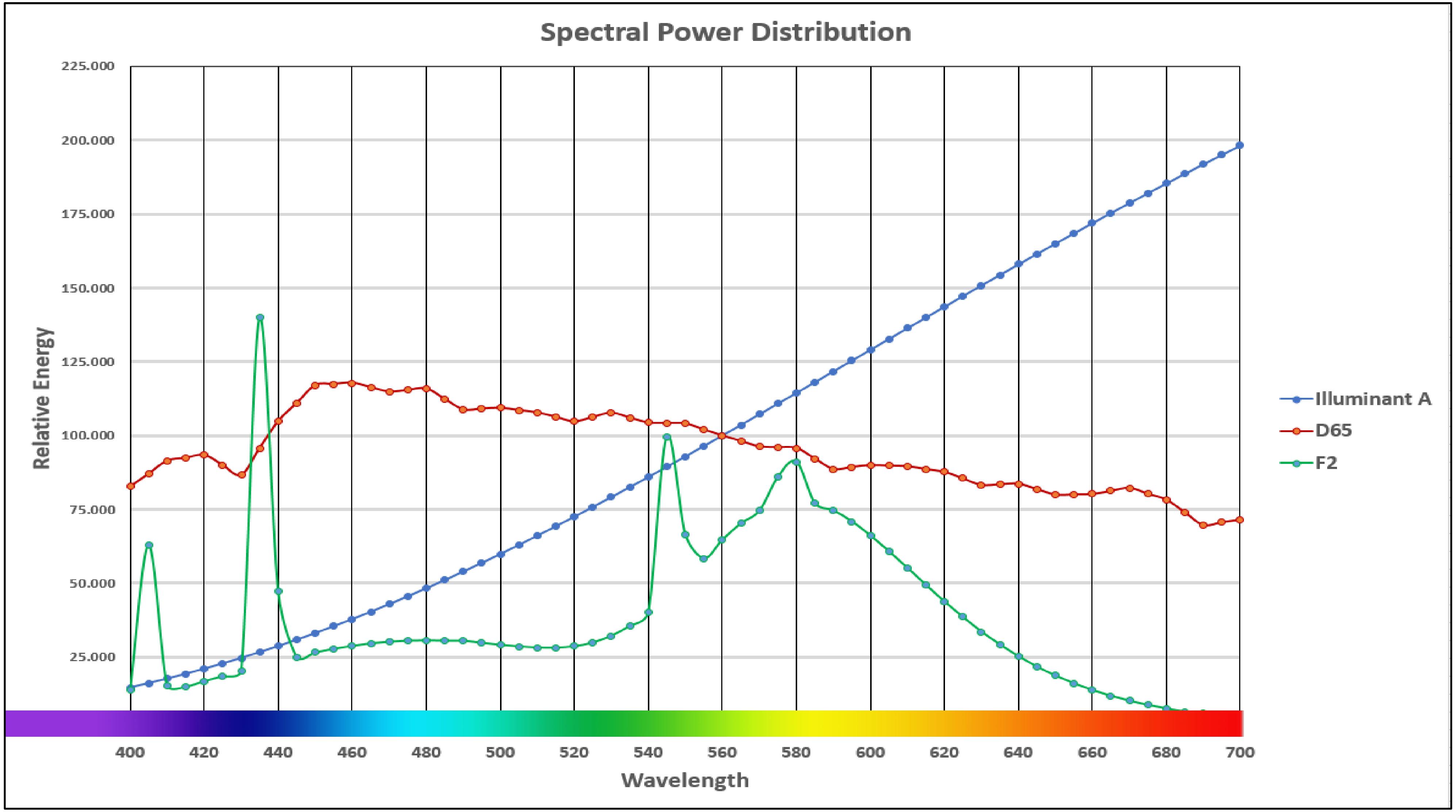

Light Source vs Illuminant

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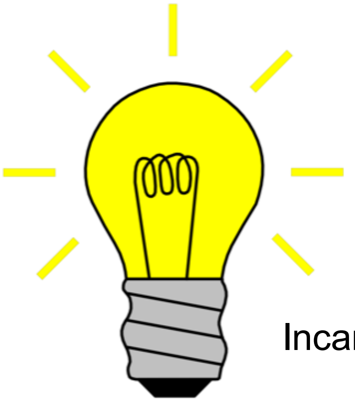
A light source is a physical object capable of producing light. The incandescent light bulb is a considered a "source".



Incandescent Light Bulb

An illuminant is a standard set of numbers that may or may not exactly represent a physical source of light. The CIE data for Illuminant A shown here represents the energy distribution of an incandescent light and is used in colorimetric calculations to provide a standard reference for color specification use.

Table T.1. Relative spectral power distributions of CIE illuminants
Relative spectral power distributions [$S(\lambda)$] of CIE standard illuminants A
λ = 400 nm to 700 nm at 5 nm intervals

λ, nm			Standard Illuminant A
400	555	96.442300	14.708000
405	560	100.000000	16.148000
410	565	103.582000	17.675300
415	570	107.184000	19.290700
420	575	110.803000	20.995000
425	580	114.436000	22.788300
430	585	118.080000	24.670900
435	590	121.731000	26.642500
440	595	125.386000	28.702700
445	600	129.043000	30.850800
450	605	132.697000	33.085900
455	610	136.346000	35.406800
460	615	139.988000	37.812100
465	620	143.618000	40.300200
470	625	147.235000	42.869300
475	630	150.836000	45.517400
480	635	154.418000	48.242300
485	640	157.979000	51.041800
490	645	161.516000	53.913200
495	650	165.028000	56.853900
500	655	168.510000	59.861100
505	660	171.963000	62.932000
510	665	175.383000	66.063500
515	670	178.769000	69.252500
520	675	182.118000	72.495900
525	680	185.429000	75.790300
530	685	188.701000	79.132600
535			82.519300
540			85.947000
545			89.412400
550			92.912000

CIE "Illuminant A" Data

Light Source Variation






3 Daylight Illuminants

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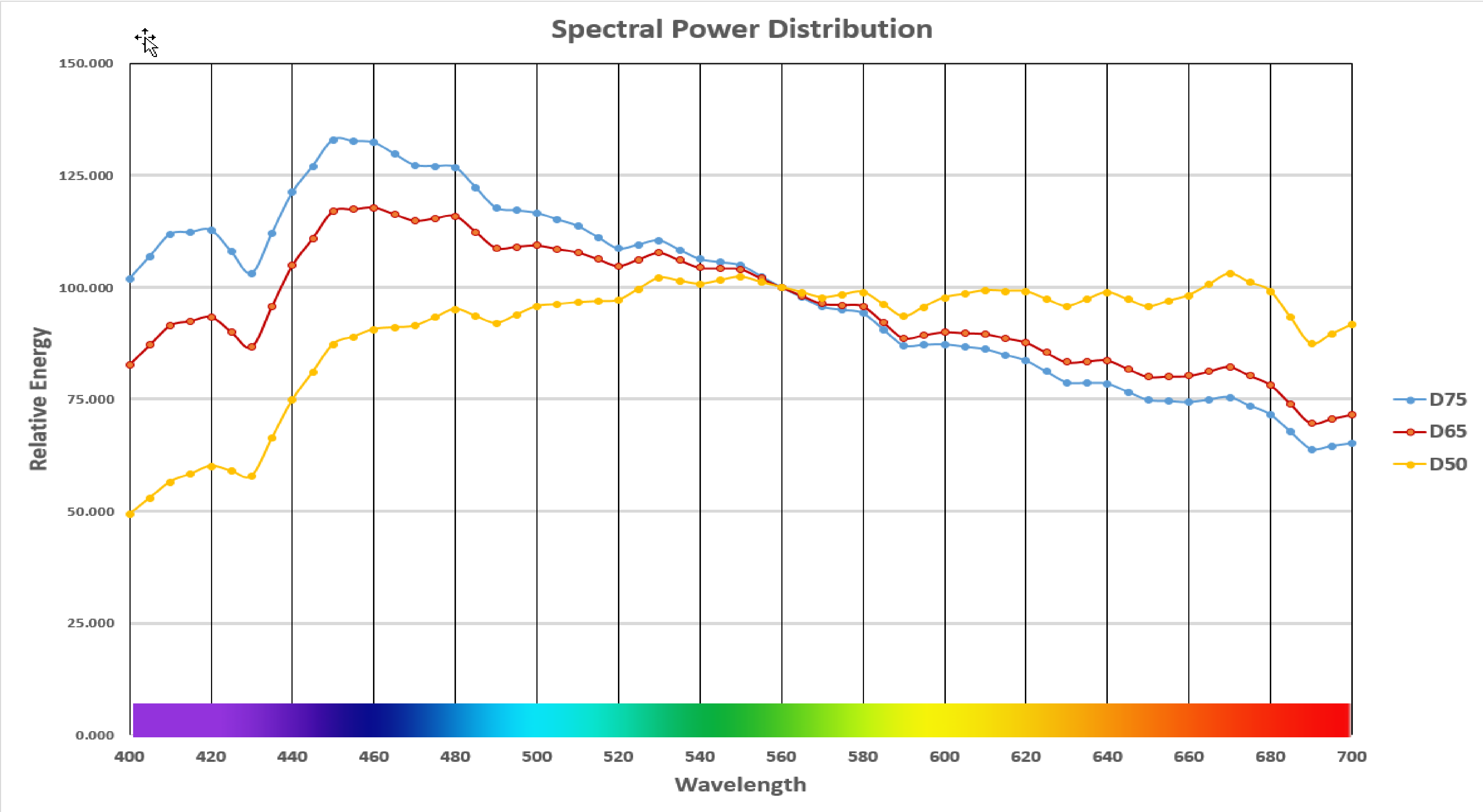

Color Temperature – Blackbody Radiation

Color temperature describes the color of a light source by comparing it to the color of a blackbody radiator at a given temperature. A blackbody is a material that will absorb all light falling on it and any radiation coming from it will depend on its actual temperature. As the actual temperature of this blackbody is raised, it radiates energy in the visible range, first red, changing to orange, white, and finally bluish white.

800K	1800K	2800K	4000K	5500K	6500K	7500K	10,000K
Embers	Candle	Incandescent	CWF	Noon Sun	Overcast Sky	North Blue Sky	

Correlated Color Temperature

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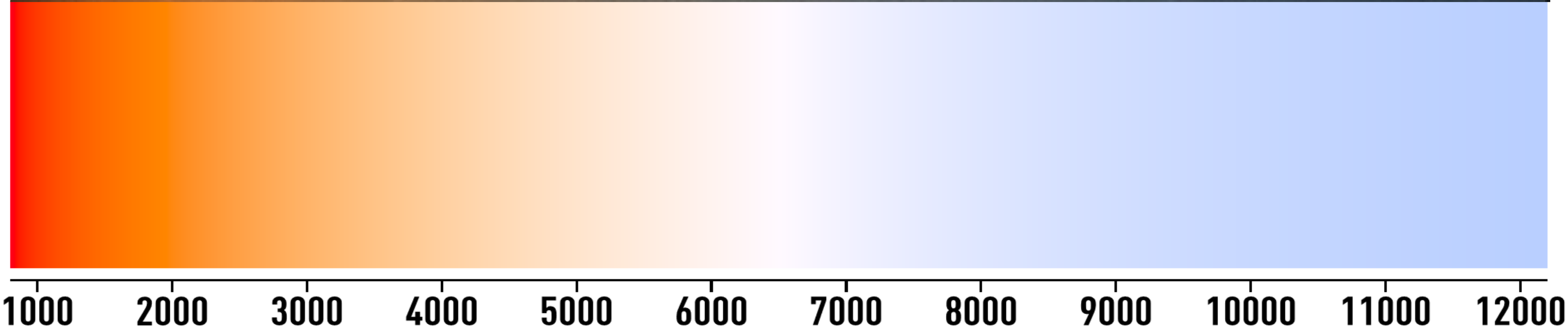

Light Sources - Summary

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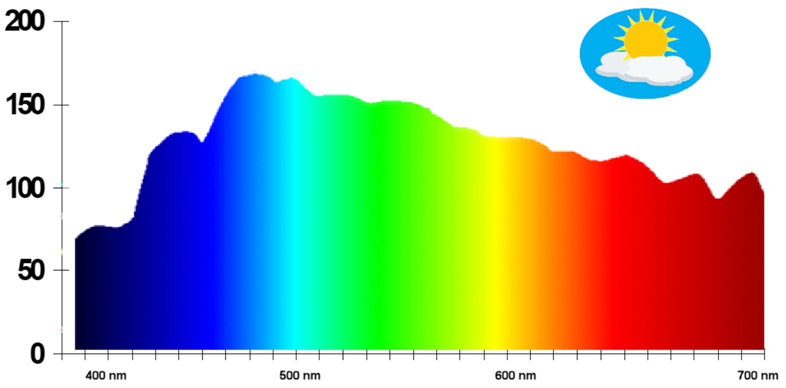
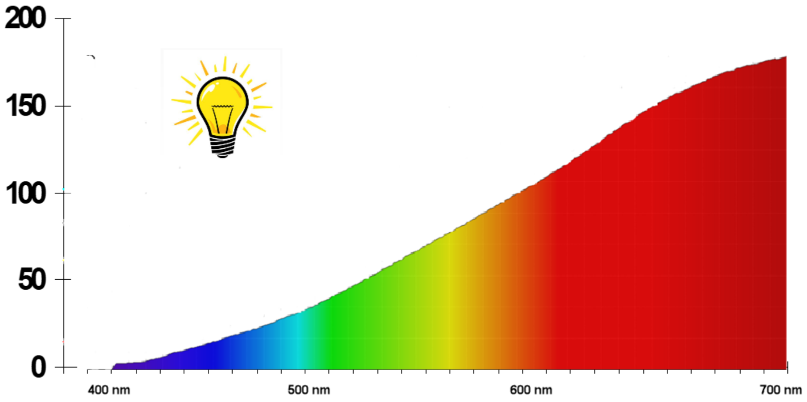
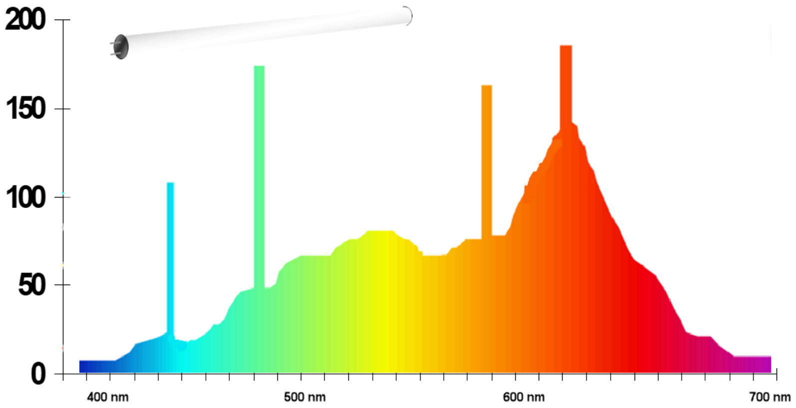
Daylight



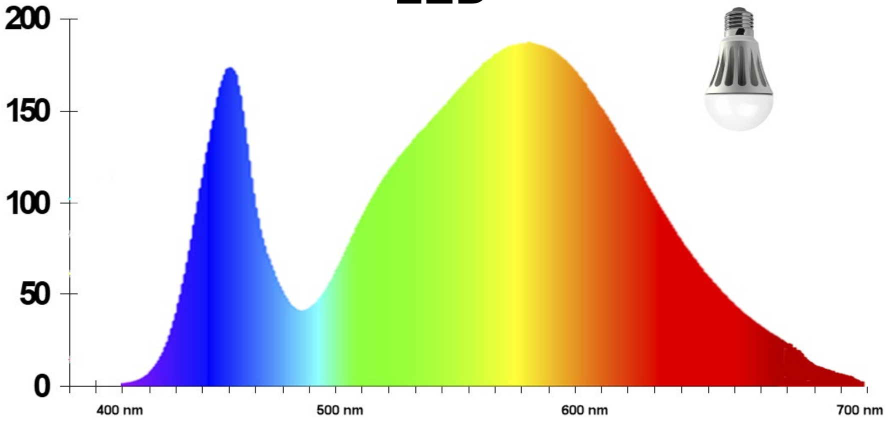
Incandescent



Fluorescent



LED



Light and Object Interaction

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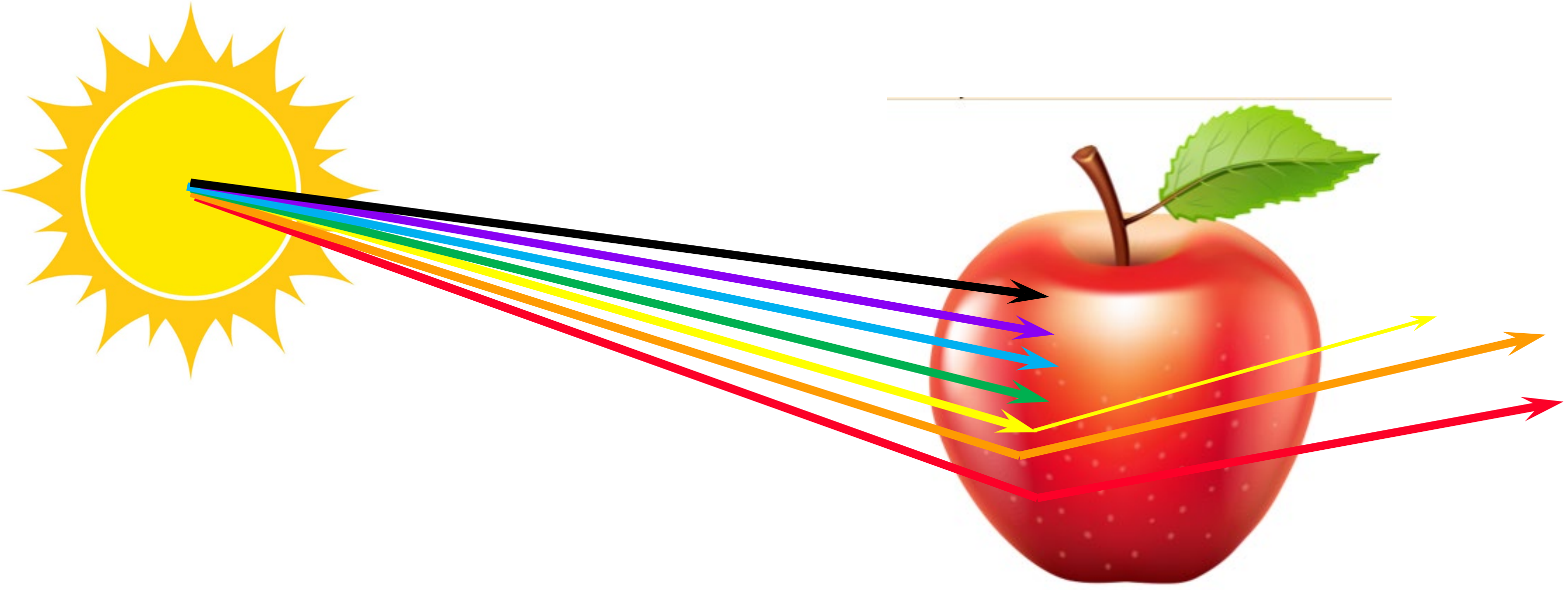

Spectral Reflectance Curve

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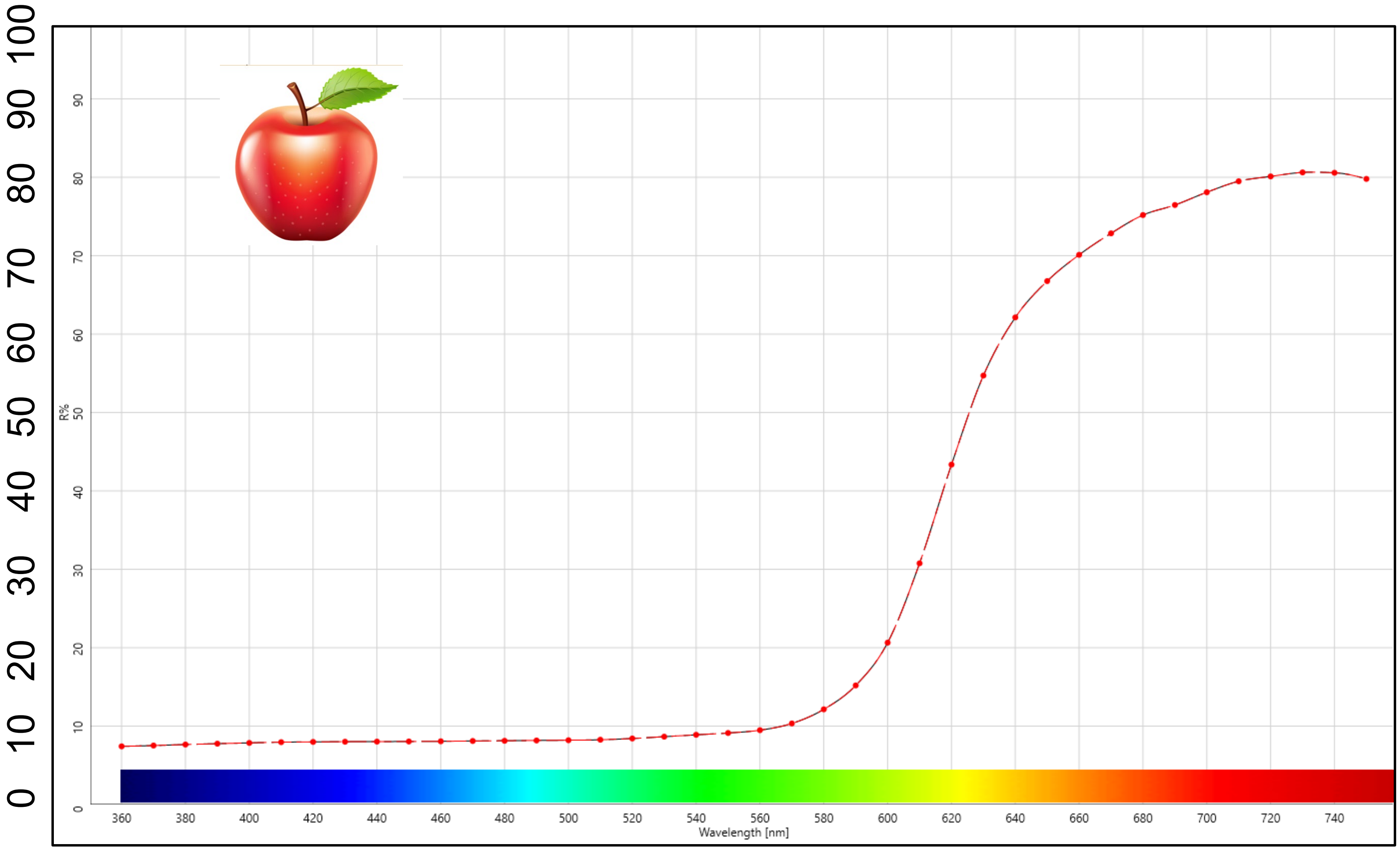
%R



Spectral Reflectance Curve

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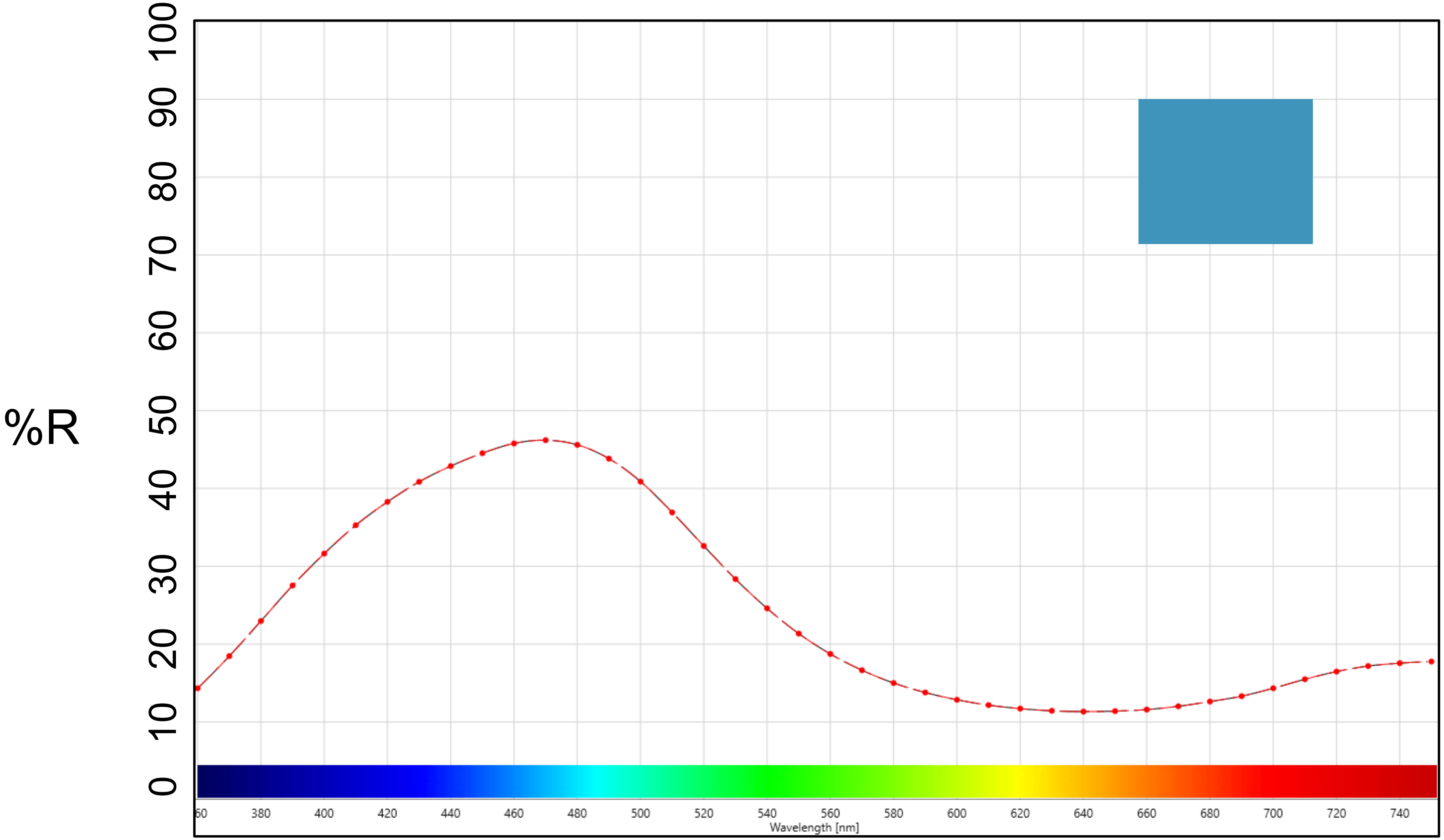
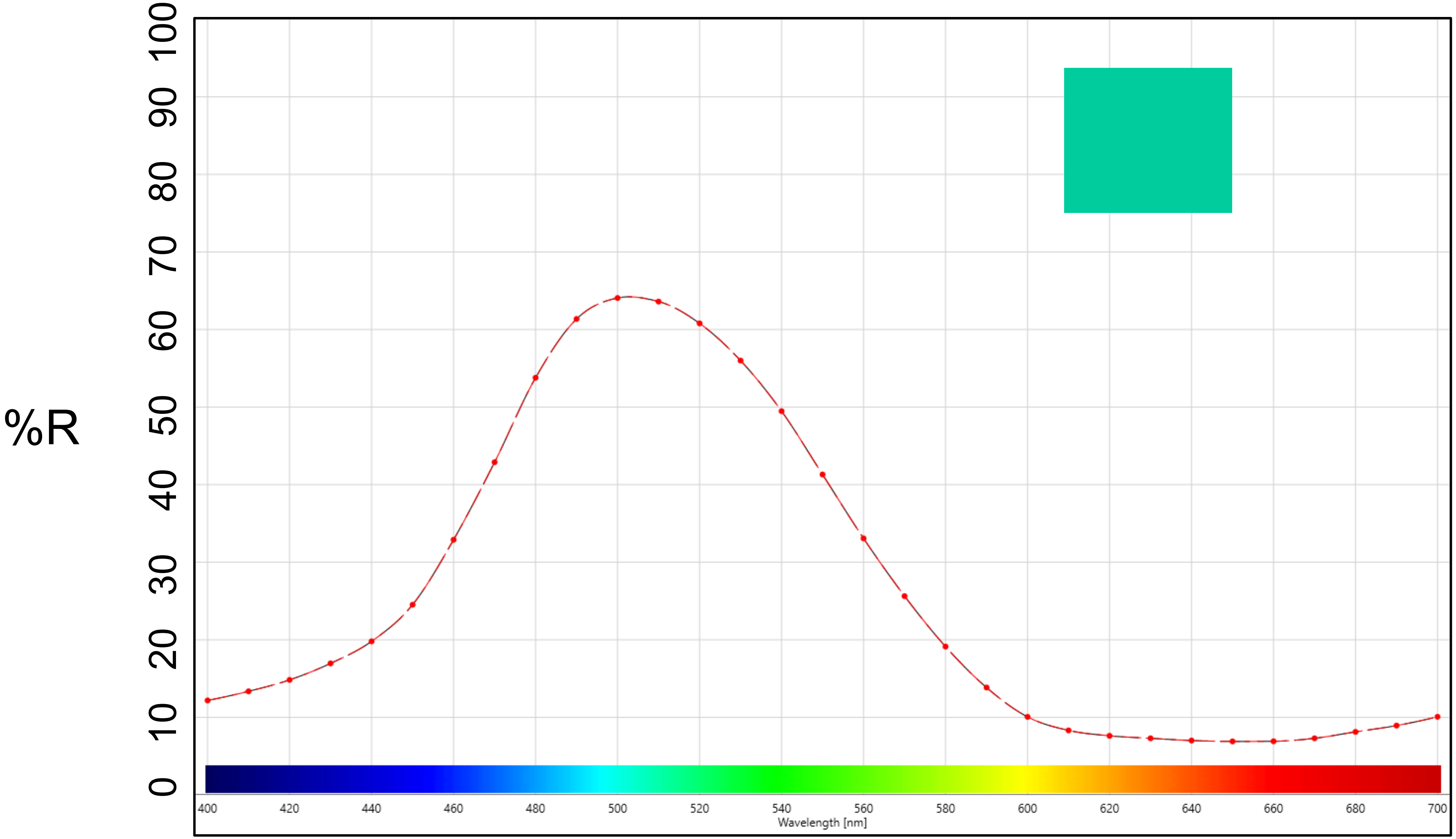
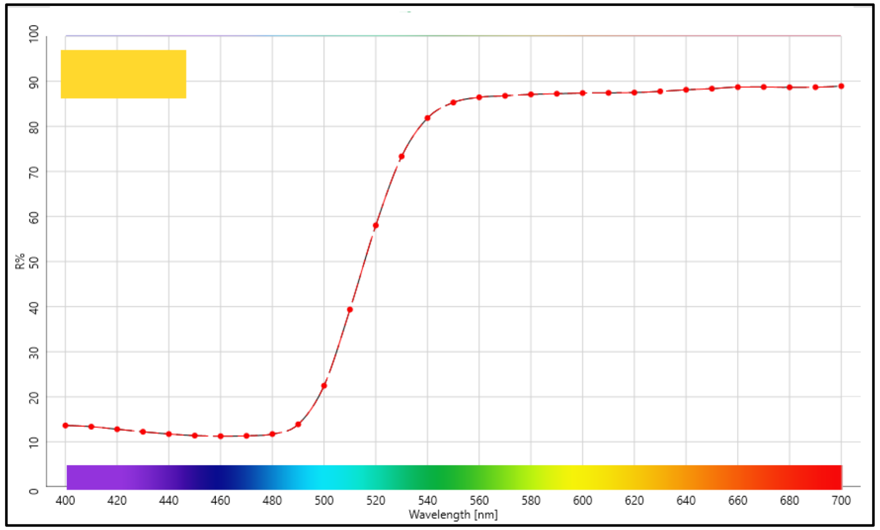


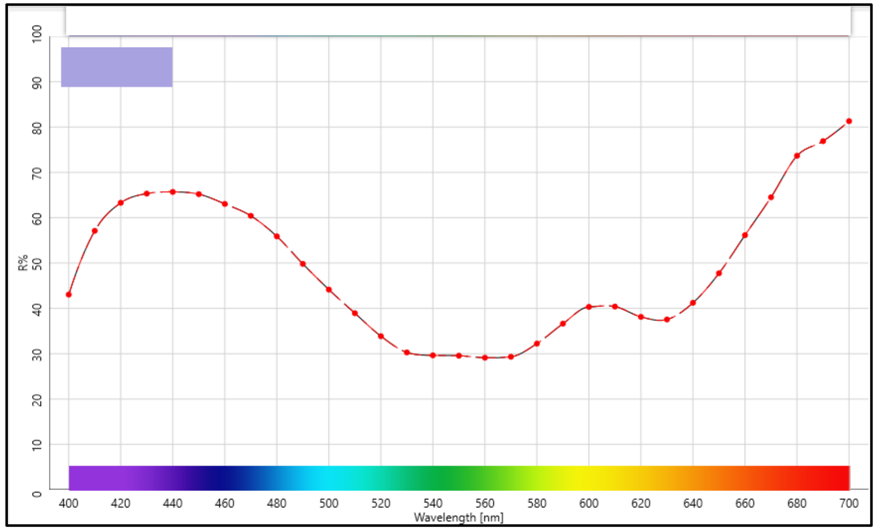
Spectral Reflectance Curve

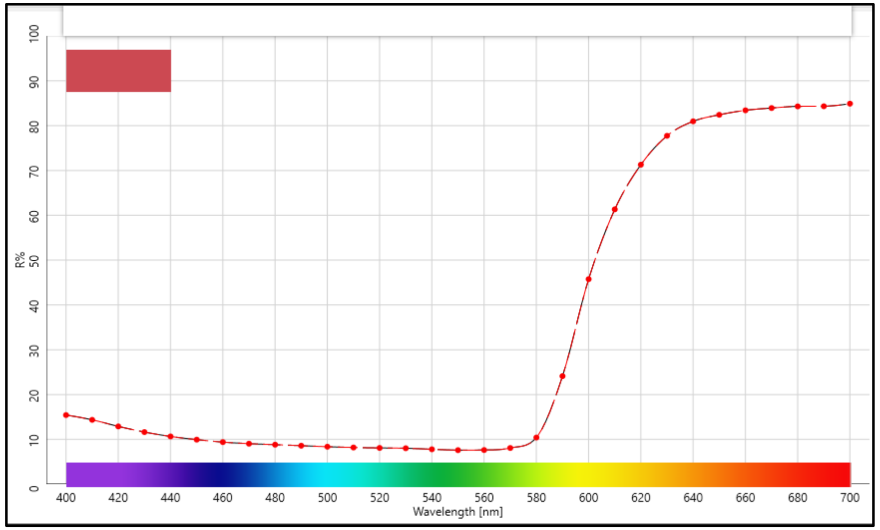
Academy

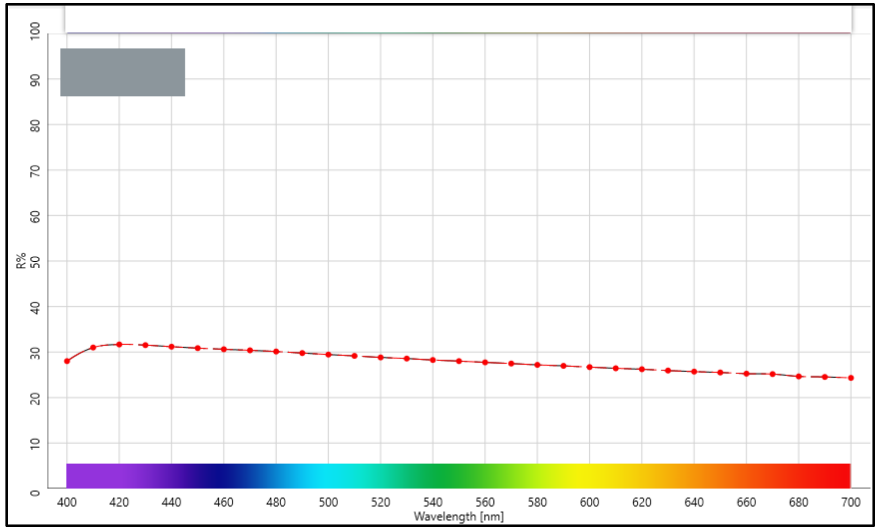


Spectral Reflectance Curves









%R – Blue and Yellow Paint

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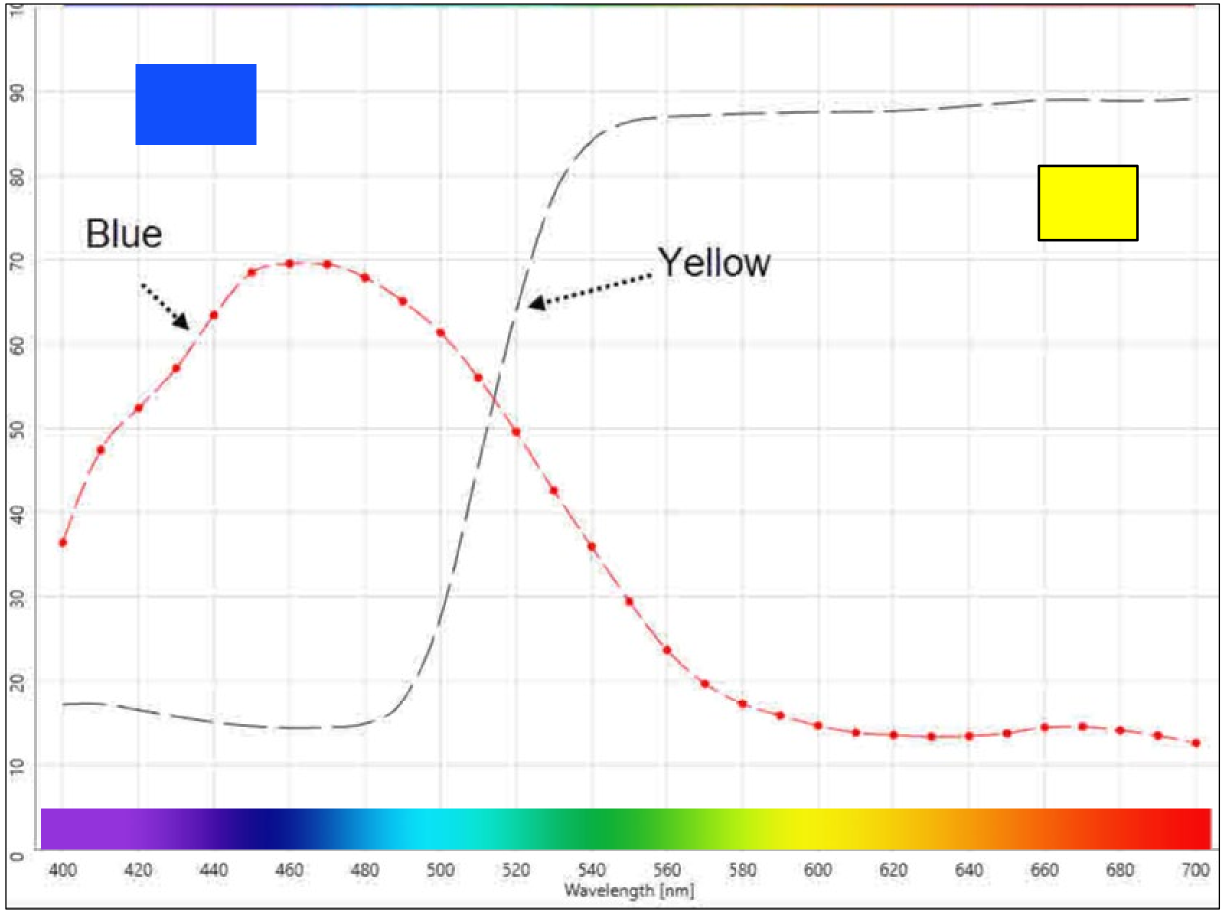
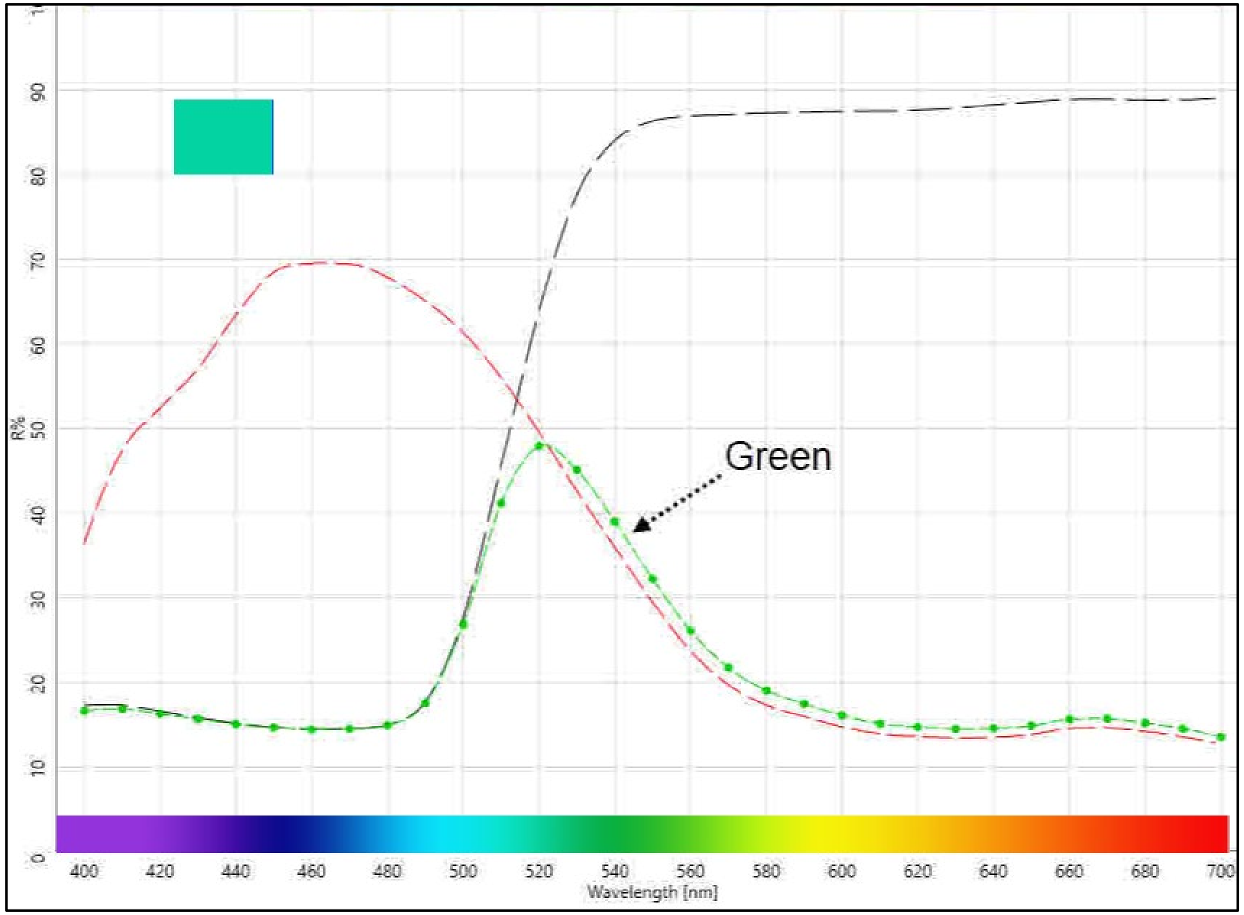
Blue and Yellow Paint





Object and Light Interactions

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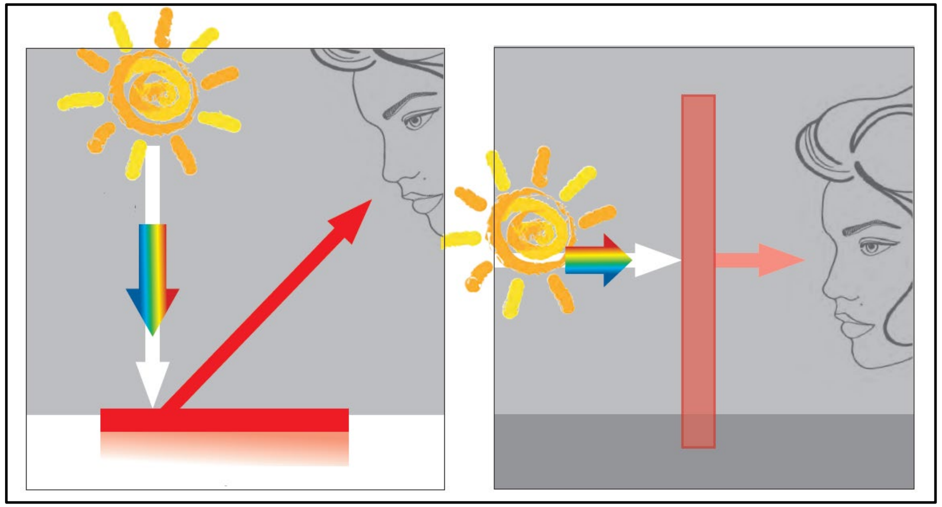
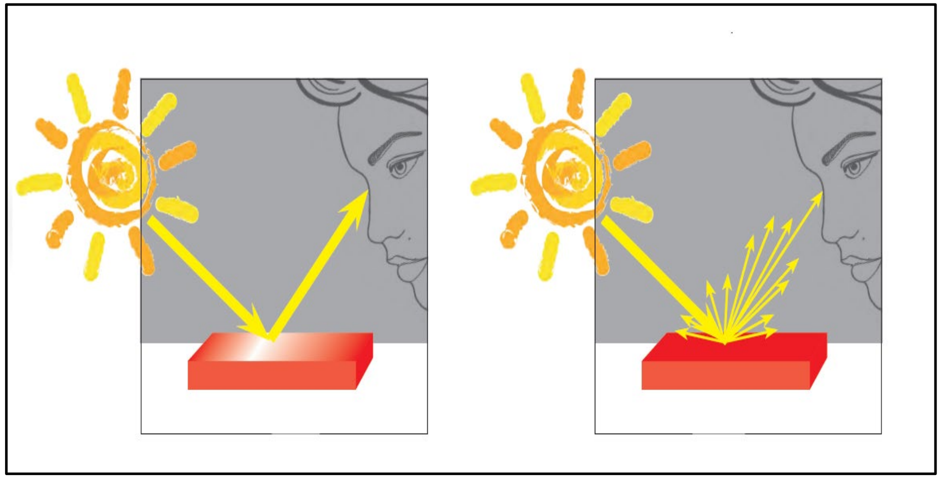
Reflection Transmission



High Gloss Matte



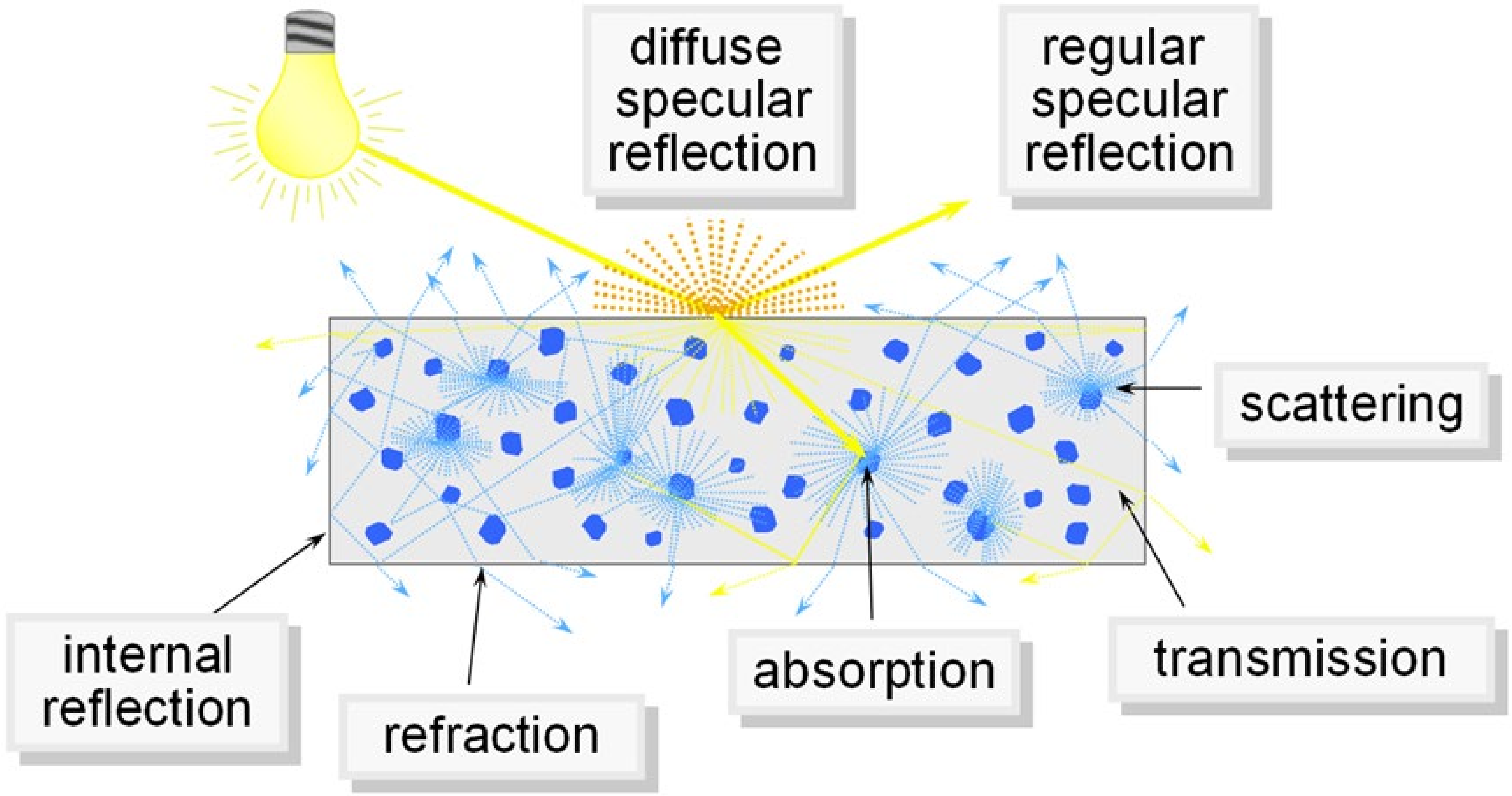
Generally, we can define 2 main light and object interaction modes: reflection and transmission. Looking at these modes in more detail, we can state that light in either mode can be absorbed, scattered or refracted. We normally distinguish between materials by the ability of light penetration.

- **Transparent** – Light can be absorbed but generally is transmitted without scattering. Light easily penetrates the material.
- **Translucent** – Light can be absorbed and scattered but can penetrate the material.
- **Opaque** – Light can be absorbed and scattered but cannot penetrate the material.

Surface Effects

A portion of light energy is reflected off the surface of an object. This is called specular reflection. It is due to the difference in the refractive index of the material and air. The type of surface (smooth vs rough) determines how the light is reflected. It can be diffuse from a matte surface or very directional from a glossy surface. Gloss is an important appearance characteristic in addition to color.

How Objects Modify Light



The Human Observer

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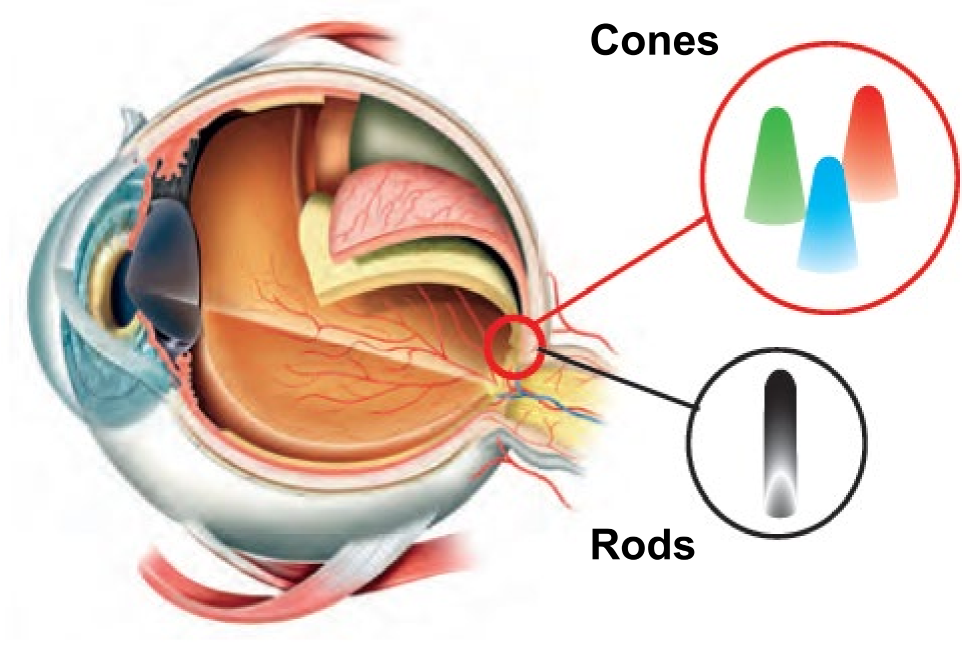
The human observer in our discussion comprises both the human eye and the brain. The eye is a data gathering structure much like a camera while the brain is where the perception of color is realized.

Visual information is sent from the eye to the visual cortex along the optic nerve. The final processing of the visual signal is completed in the visual cortex and in other areas of the brain.



The Human Eye

Light enters the eye through the cornea.

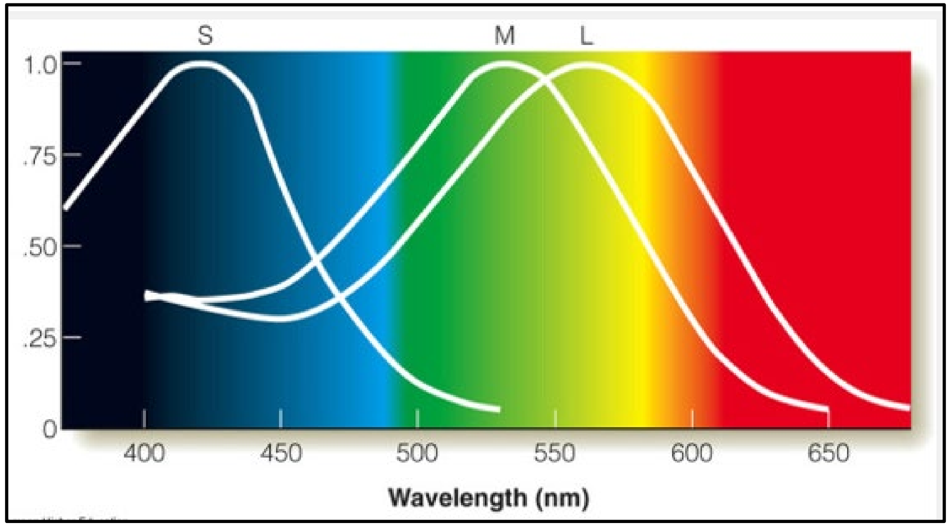
The amount of light entering is controlled by the pupil.

The lens helps to focus light on the retina.

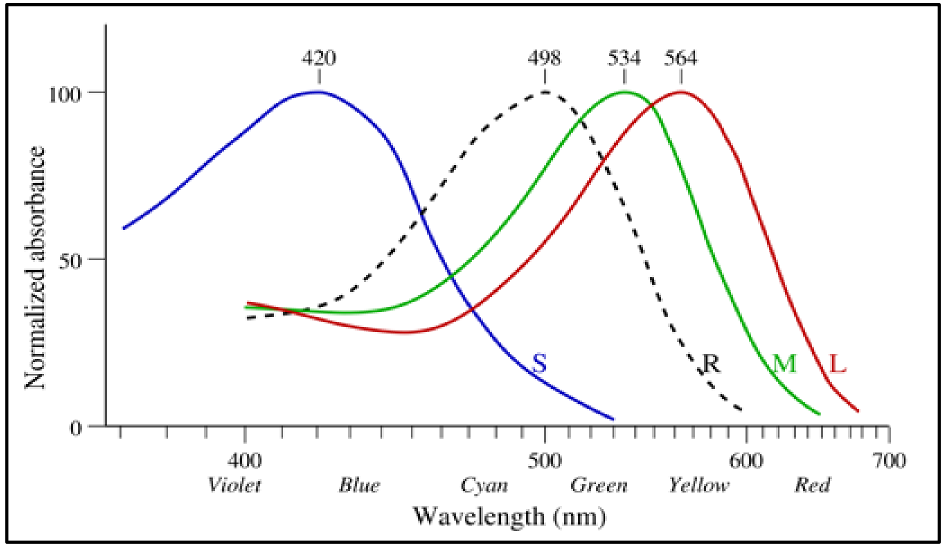
The retina is a complex part of the eye that converts light into signals that the brain can understand.

The retina is packed with photosensitive cells called rods and cones.

Rods and Cones



Cone cells are responsible for (photopic) color vision and color sensitivity. Six to seven million cone cells are found in the retina of a human eye. There are three types, L-cones, M-cones and S-cones, which have three different types of photosensitive pigments. L-cones respond to light of long wavelengths such as red, M-cones respond to medium wavelengths such as green, and S-cones respond to light of short wavelengths such as blue.



Rods are responsible for dark adapted (scotopic) vision. They are 1,000 times more sensitive than cones and better at detecting rapid movement. There are about 120 million rods in the retina. They do not detect color and are predominantly found in the peripheral areas of the retina.

Trichromatic and Opponent Theory

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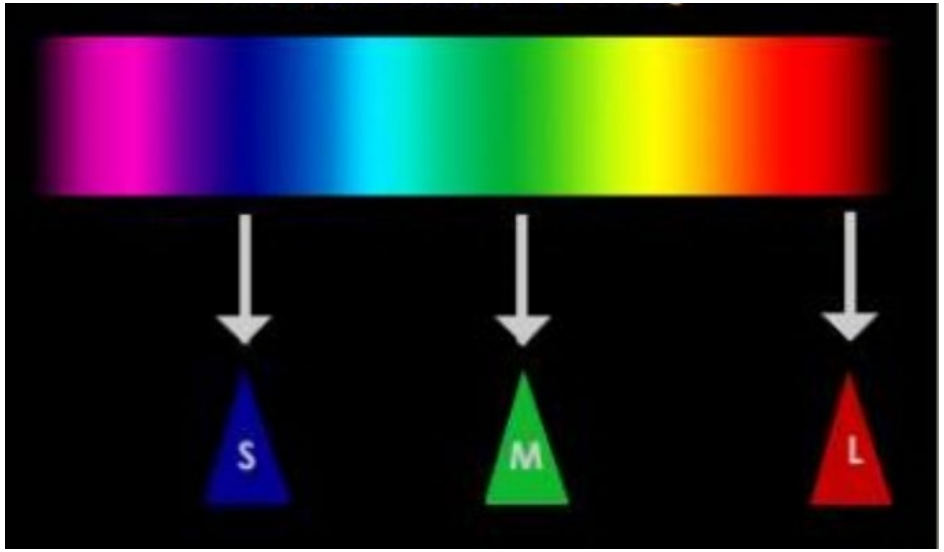
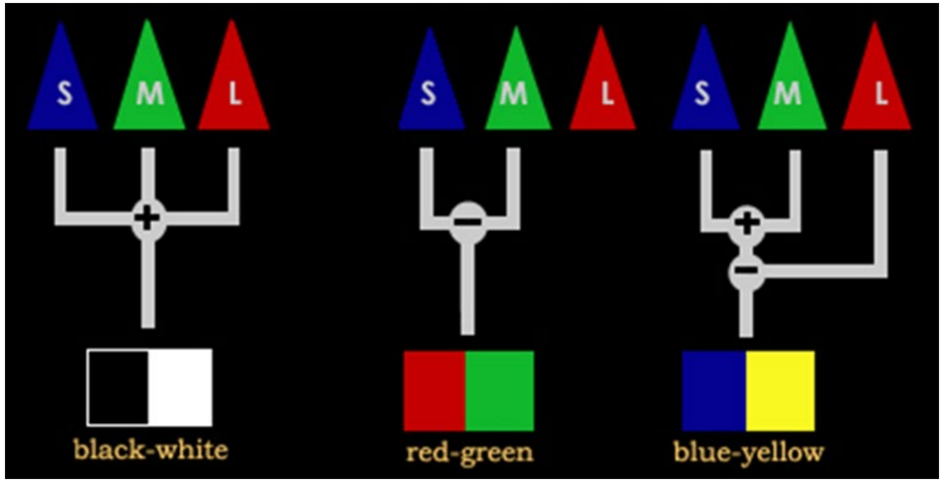


Young-Helmholtz or Trichromatic Theory

Thomas Young, in 1802 proposed that there are three types of photoreceptor cells in the eye that are sensitive to red, green and blue light and that these 3 cells allow the eye to perceive all colors.

Hermann von Helmholtz further developed this theory in 1850, stating that the cone photoreceptor cells were either short-wavelength (blue), medium-wavelength (green), or long-wavelength (red).



Opponent Theory Proposed by Ewald Hering in 1878

Hering said that color vision takes place in three channels where opposite or complementary colors are in competition. The visual system is responsive to three color pairs which are red-green, blue-yellow, and black-white. Color vision is a result of the combined response of these components. His theory suggested that the colors in each pair oppose each other.

Which Theory Is Correct?

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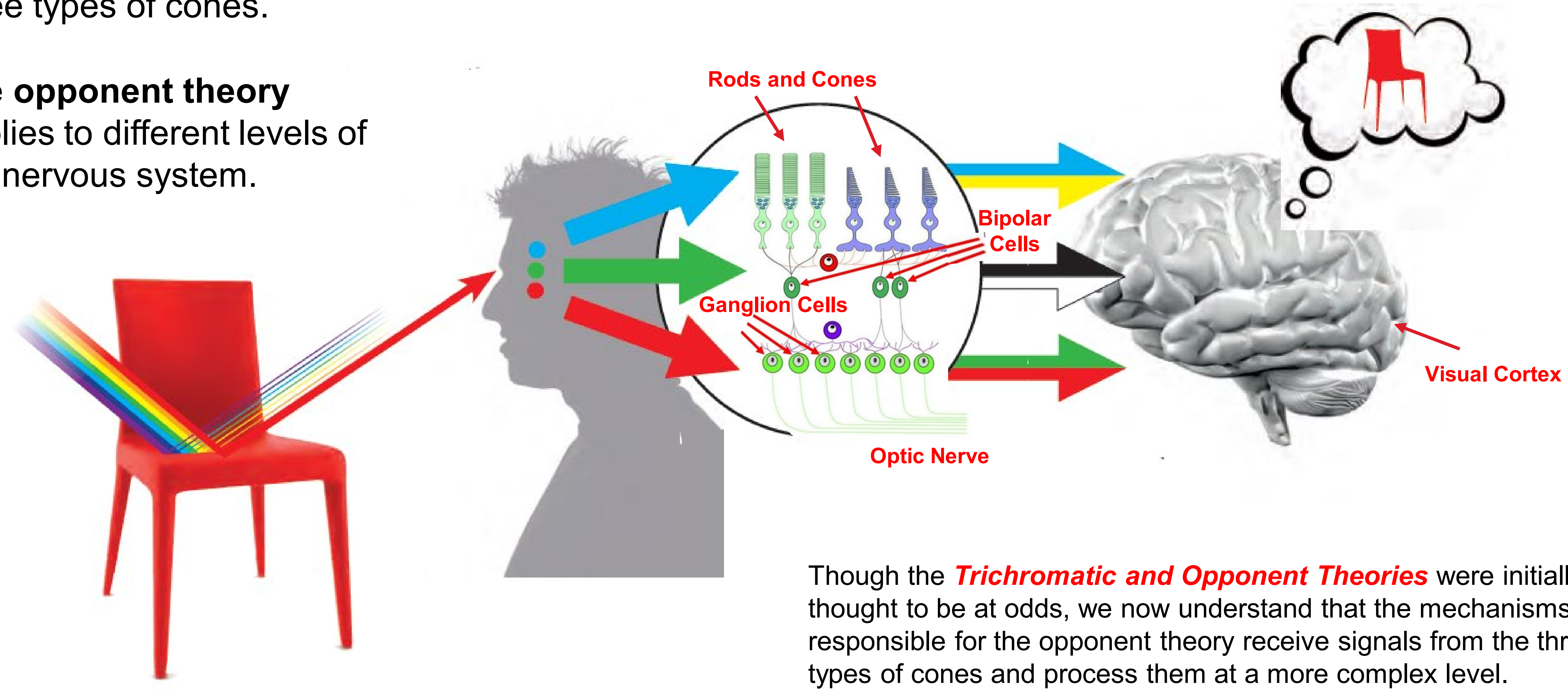
Both theories are needed to explain the complexity of color vision.

The **trichromatic theory** defines the way the retina of the eye allows the visual system to detect color with three types of cones.

The **opponent theory** applies to different levels of the nervous system.



Though the ***Trichromatic and Opponent Theories*** were initially thought to be at odds, we now understand that the mechanisms responsible for the opponent theory receive signals from the three types of cones and process them at a more complex level.

Complementary Afterimage

Visual demonstration of the opponent color process

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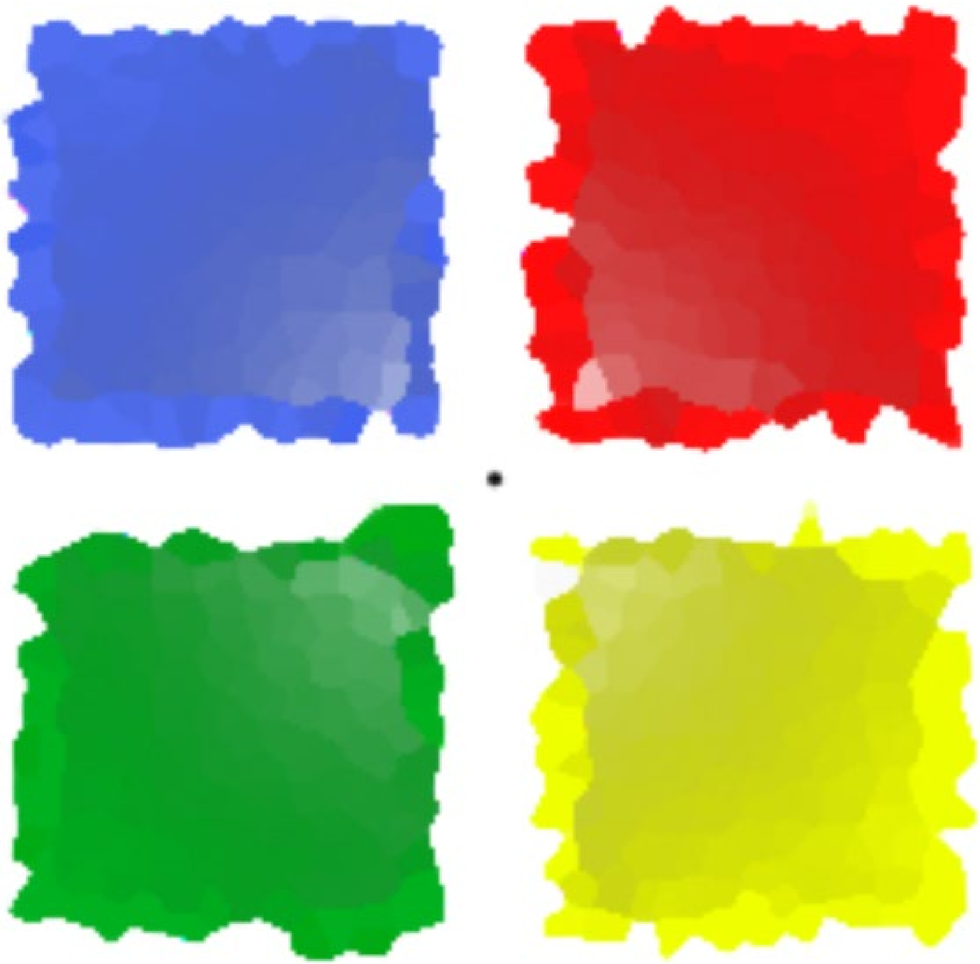

Afterimage

Complimentary colors are seen

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Original Picture

Afterimage

Additive and Subtractive Primaries

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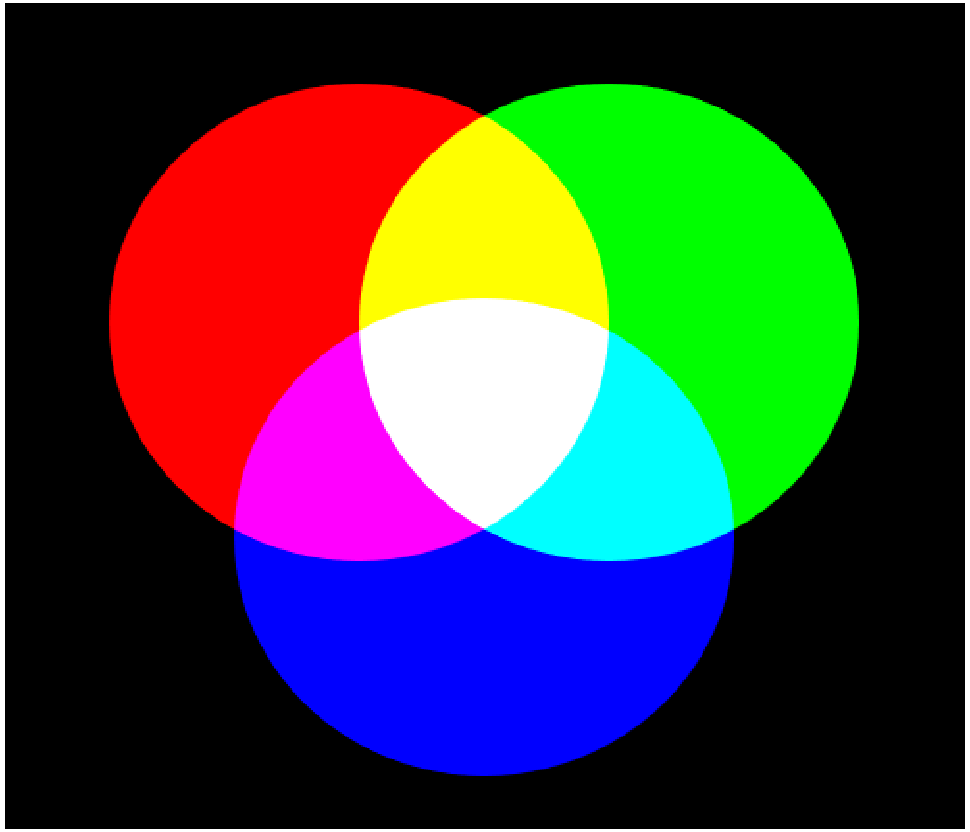
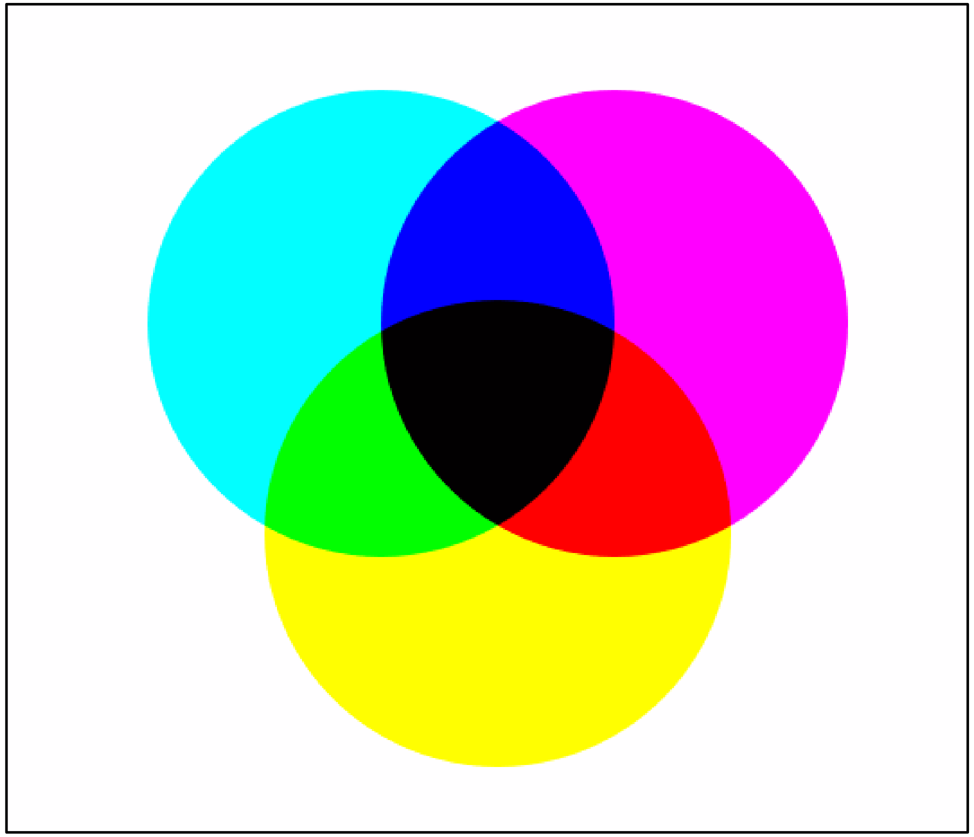
Additive Primaries - Mixtures of Light



RED GREEN BLUE

Subtractive Primaries - Mixtures of Pigments



CYAN MAGENTA YELLOW

Webinar – Final Comments

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

Light Source

Object

Observer

In our next webinar, we will see how we can take this concept of light, object and observer as a color perception and build a colorimetric or numerical specification.

Next session:

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We will talk about how we describe and communicate color

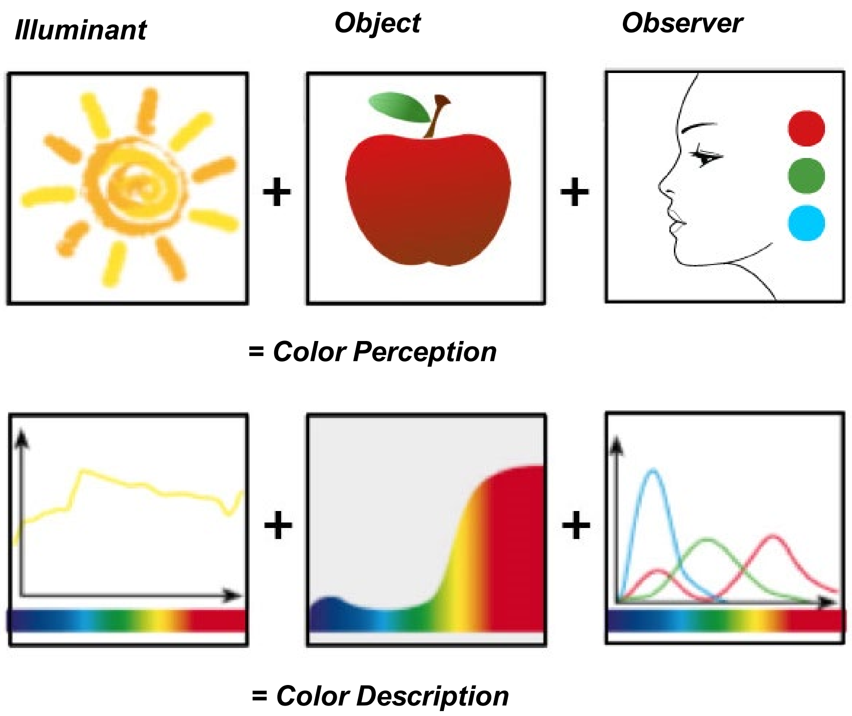
CIE Standard Observer

Tristimulus Values

Metamerism

Color Order Systems

Color Descriptions – Hue, Chroma and Lightness



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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?

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