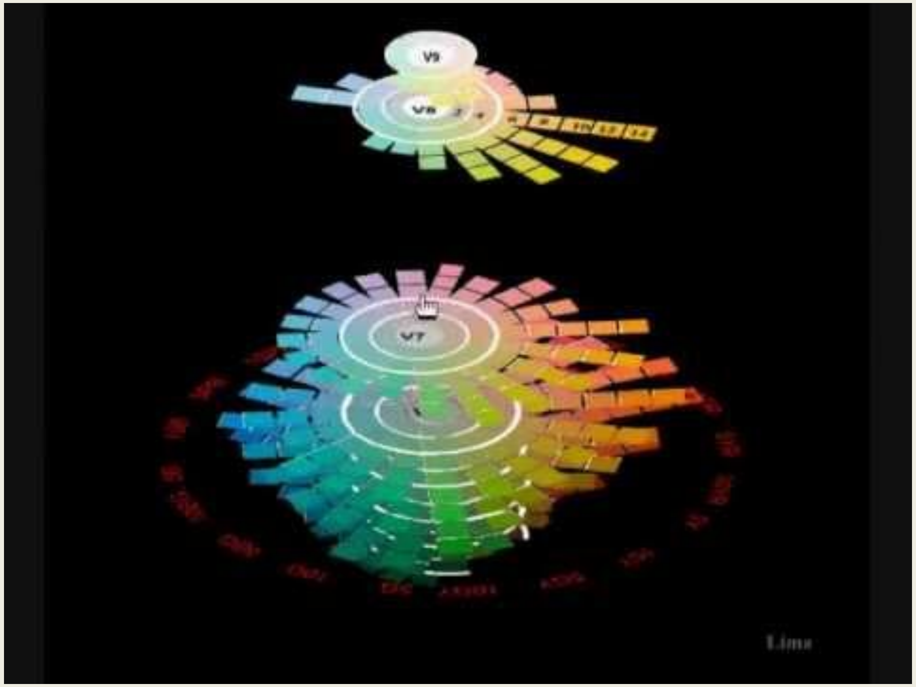
Color in Graphic Arts and Printing



Athens 2023 Antigoni Karamani

The perception of color

Colors are the biggest “grace to the light", skillfully hidden within his white nature
Giorgos Grammatikakis

Perception of color

- Light source
- Object
- Optical system

The perception of color

- The meaning of color refers to the phenomenon of the natural transformation of light that is reflected by objects and becomes visible, due to the color sensitivity of the human eye, through a particularly complex process. This sensory perception presupposes the existence of three factors:

- the light source,

- the object, whose properties determine the reflection and propagation of the incident light, and

- the visual system, which for humans is the eye-brain combination

The nature of light

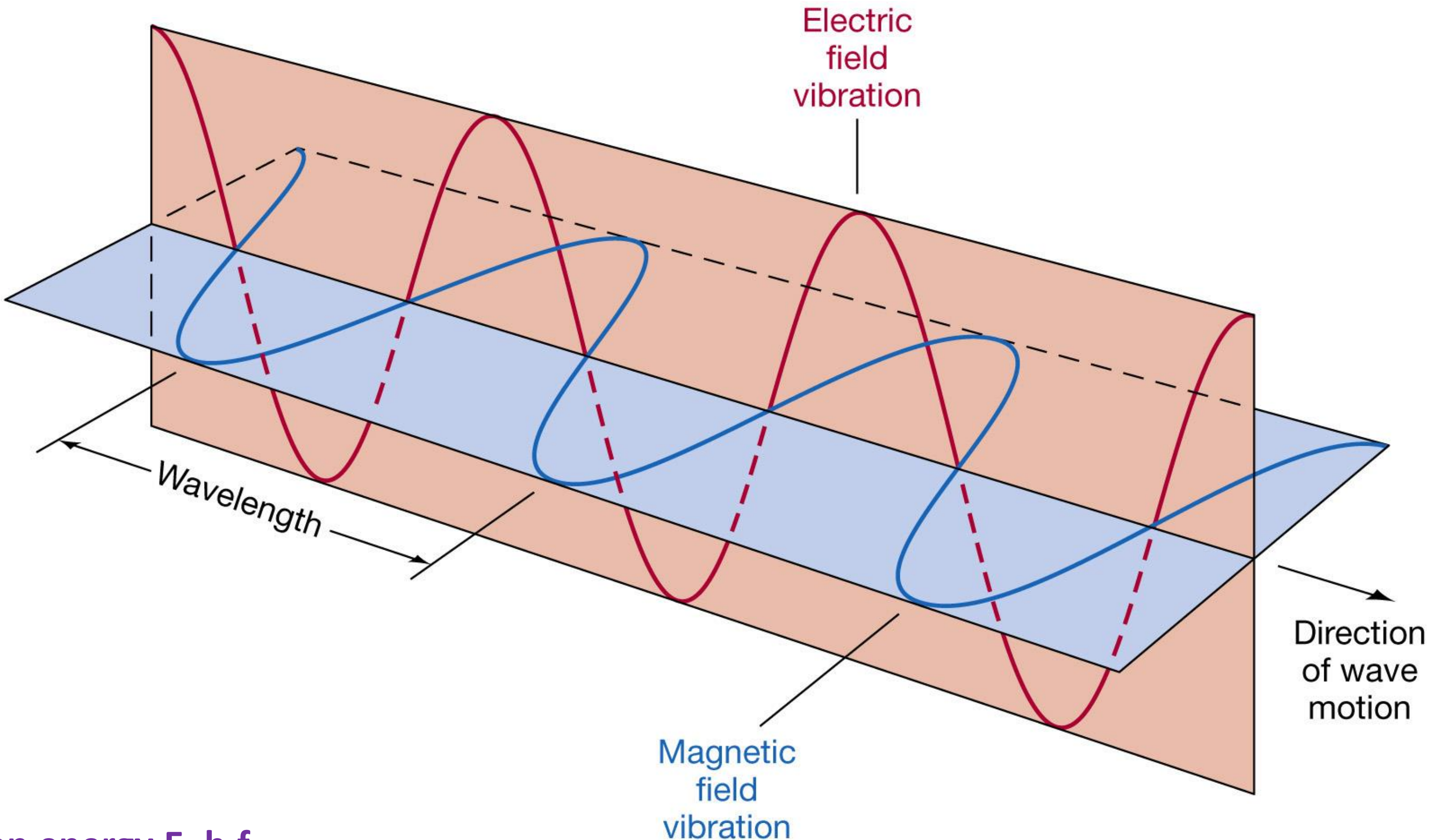
Maxwell's electromagnetic theory

- Light is an **electromagnetic wave,** produced by vibrations of the electrically charged components of the atoms of matter.
- During the propagation of electromagnetic waves, electric and magnetic field **energy is transferred**
- **Wavelength:** is the distance between two adjacent crests (or troughs) of the waveand is given in meters or in smaller denominations, including nanometers.

The **nanometre** is a unit of length in the International System of Units (SI), equal to one billionth of a metre (0.000000001 m, $\mathbf{1\times10^{-9}\ m}$).

Wavelength is commonly designated by the Greek letter lambda (λ).

The nature of light



Photon energy E=h·f

E: is energy (Typically in Joules)

h: is the Planck constant, $h=6.63\cdot10^{-34}$ J·s-1.

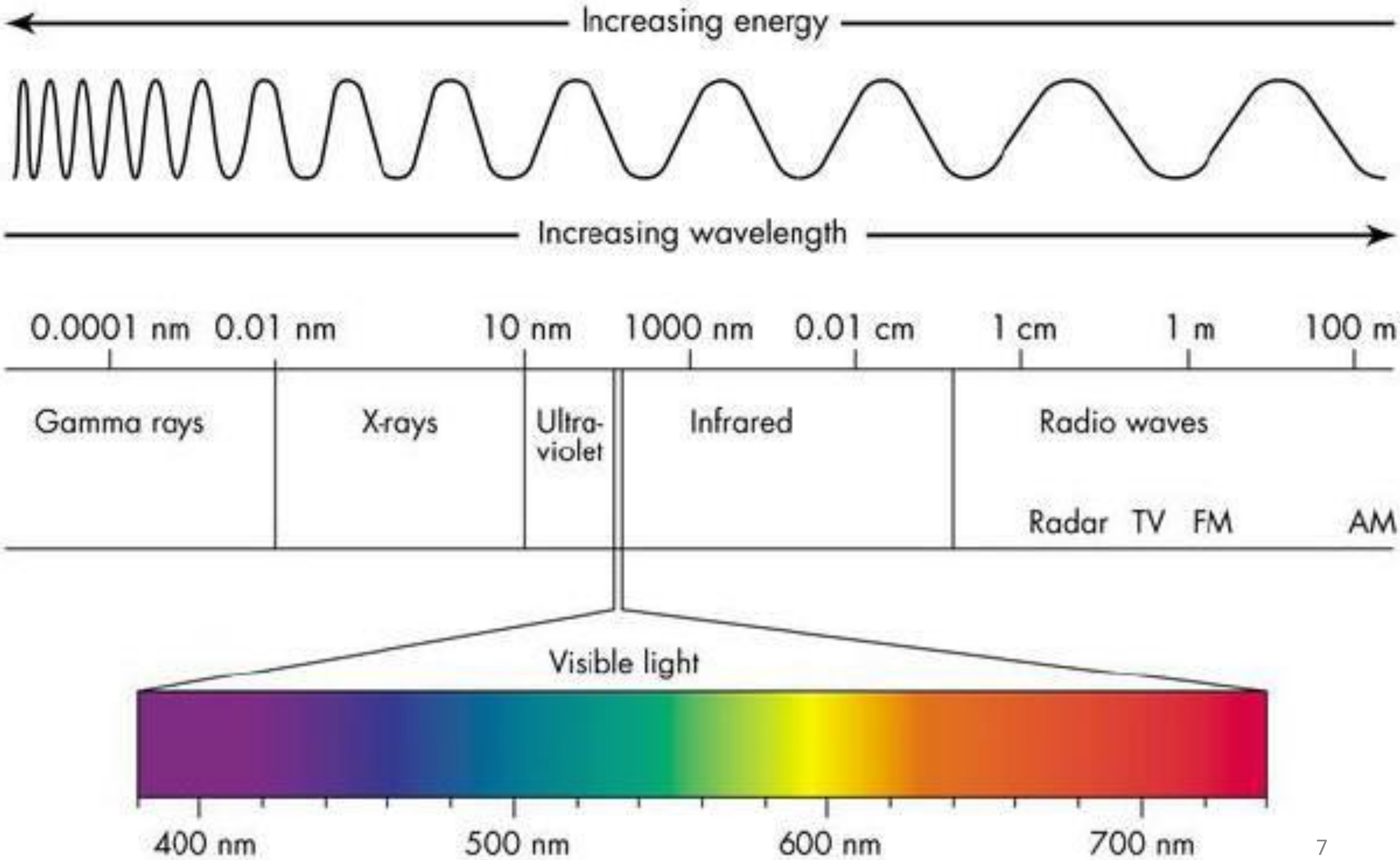
f: is photon frequency (Typically in Hertz,

the number of oscillations of the field per second)

The nature of light

- **Electromagnetic spectrum:** the range of energy levels (wavelengths) that photons have.
- **Visible spectrum:** extends from 380nm to 770nm. **Different wavelengths** cause **different sensations** of color starting from violet (with the shortest wavelengths at 380nm) to red (with the longest wavelengths at 770nm).

The electromagnetic and visible spectrum



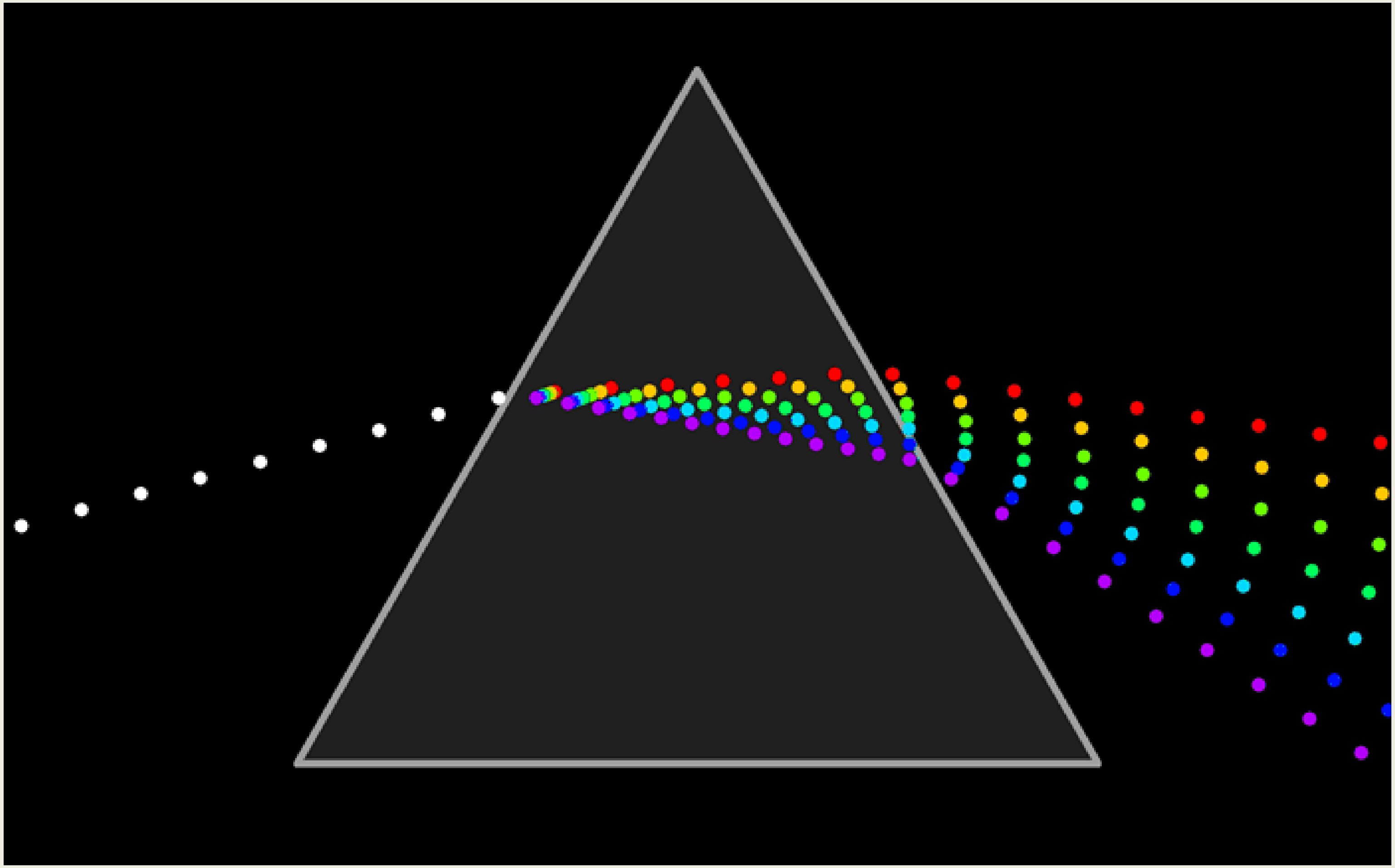
The electromagnetic and visible spectrum

Color	Wavelength (nm)	Frequency (Hz)
red	~700-635 nm	~430-480 THz
orange	~635-590 nm	~480-510 THz
yellow	~590-560 nm	~510-540 THz
green	~560-520 nm	~540-580 THz
cyan	~520-490 nm	~580-610 THz
blue	~490-450 nm	~610-670 THz
violet	~450-400 nm	~670-750 THz

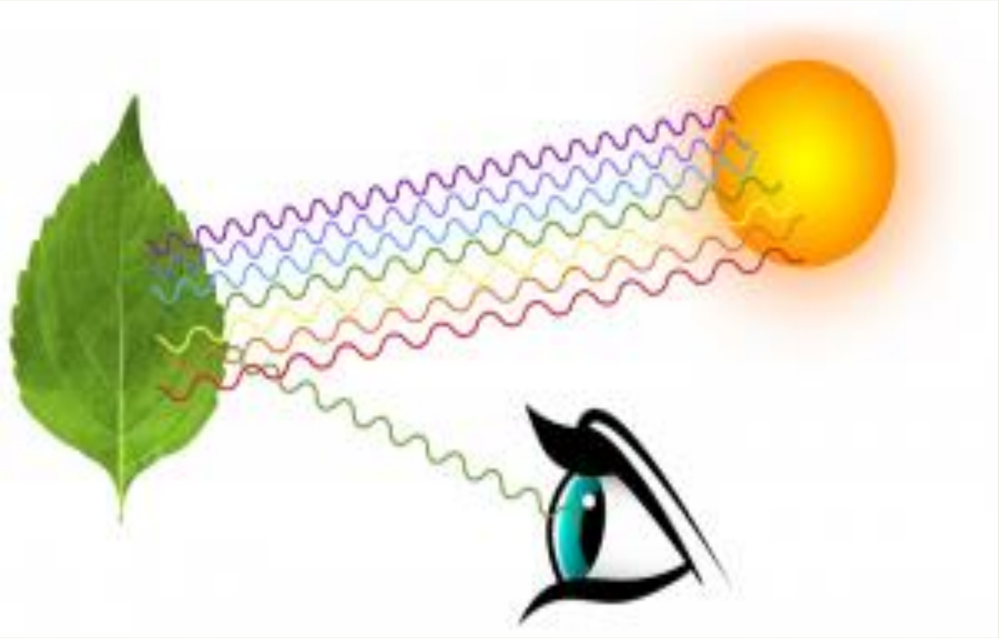
The nature of light

- Under certain conditions it is possible to analyze the wavelengths of white light individually.
- The discovery of Isaac Newton (1660), is easily carried out in a laboratory. Newton by using a glass prism and refracting through this light was able to project the resolution of all frequencies of light between 400nm and 700nm, which appears as a color spectrum from which seven colors are separated that mix successively from violet to red

The nature of light



The perception of color



- Source of visible electromagnetic energy
- Radiation emitted by the light source
- An object whose chemical properties modify electromagnetic energy
- Human visual system The modified action:

- Focused by the eye (recording of stimulus in the sensory organ-image on the retina)
- Generation of electrical signals by the receptors
- Transfer of signals from specialized neurons
- Arrival of signals to the brain
- Analysis of signals from the brain
- Perception of the external object

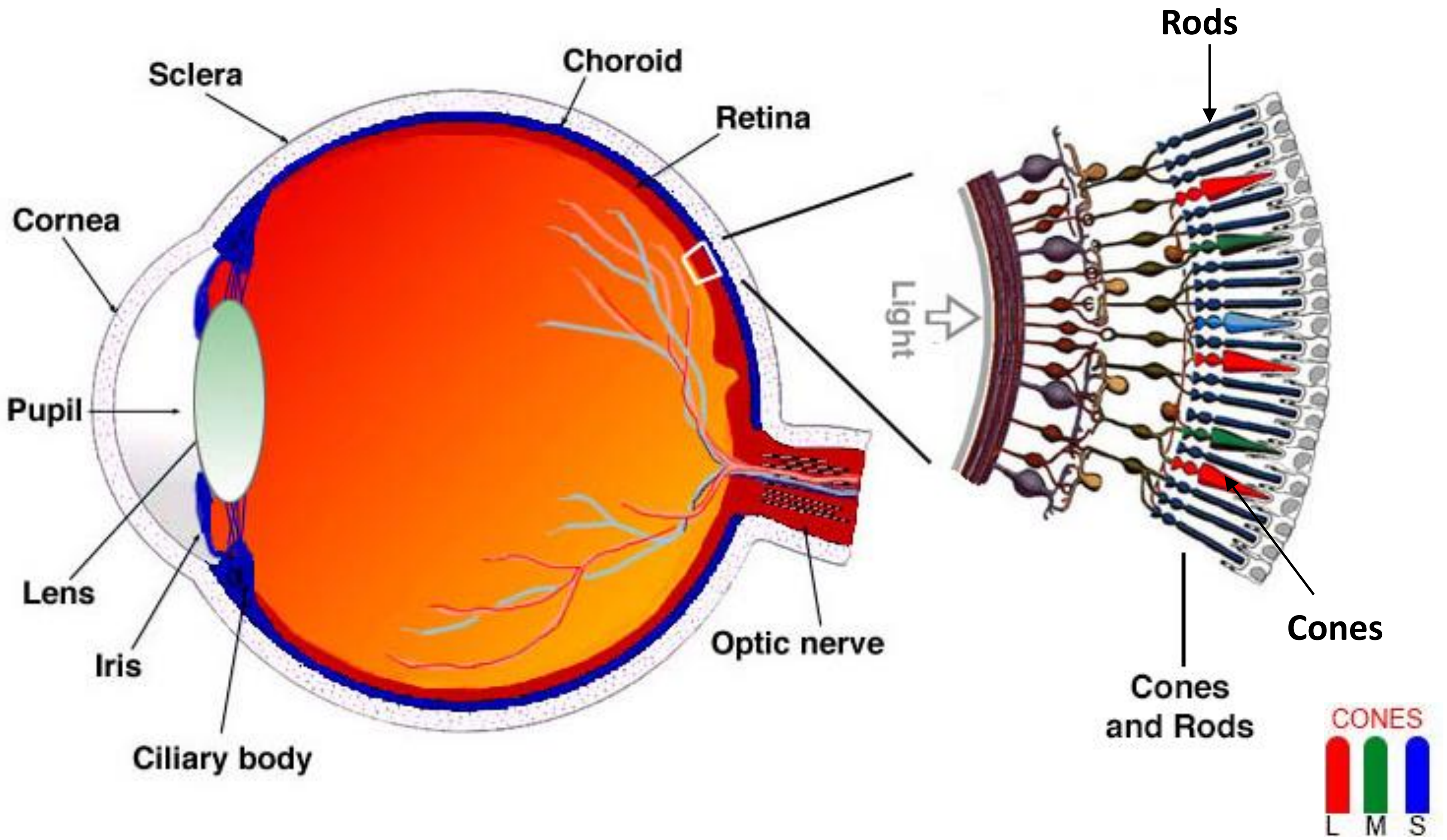
Human visual system

The human eye is made up of:

- an **optical part,** which focuses the optical image on the photosensors (photoreceptors) and
- a **neural section** which converts the visual image into a given sequence of neural discharges.

Photosensors are only sensitive to that small part of the broad spectrum of electromagnetic radiation, **visible light**. Light radiation of different spectral power distribution, always within the limits of the visible spectrum, is perceived as different colors.

The Human eye



Human visual system

In the retina of the human eye there are two types of photoreceptors:

Rods: About 120 million

They are located around the retina

They have a cylindrical shape

Responsible for vision in low light levels,

due to their high sensitivity

Cone: Less than sticks, about 6 – 7 million

Large concentration in the center of the retina

Less sensitivity to low light

Responsible for color and sharpness of perception

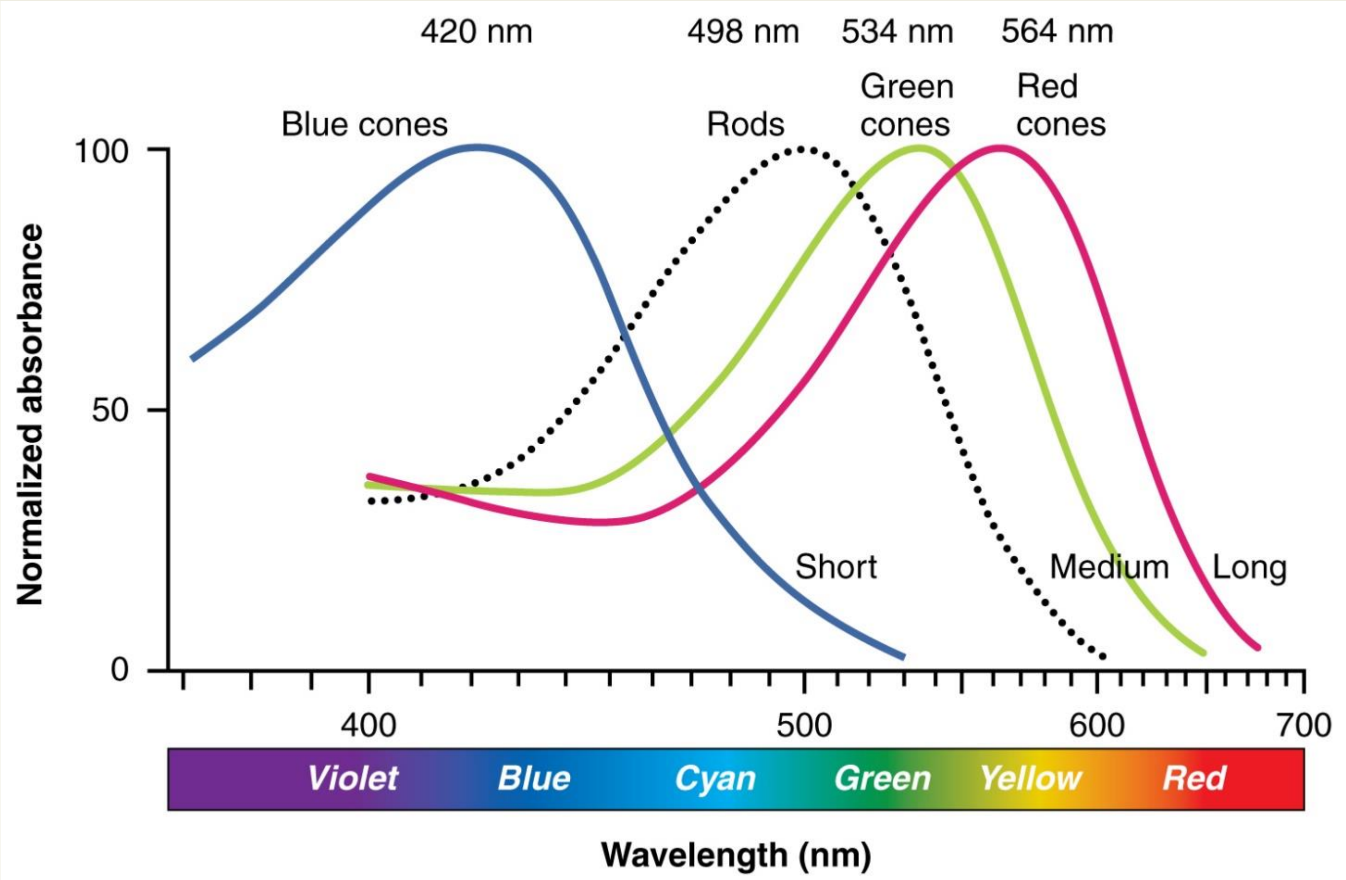
Human visual system

There are three different types of cones that react differently to wavelengths of light

- **S-cone (Short):** sensitive to photons of short wavelength maximum sensitivity at a wavelength of about 4,450 Å (445 nm). They are sensitive to **blue** to medium wavelength photons maximum sensitivity at a **light**.
- **M-cone (Medium):** sensitive wavelength of about 5,400 Å (540 nm). They are sensitive to **green light.**
- **L-cone (Long):** sensitive to long-wavelength photons and maximum sensitivity at a wavelength of about 5,770 Å (577nm). They are sensitive to **red light.**

* The **angstrom** or **ångström** (Å) is a metric unit of length equal to 10^{-10} m or 0.1 nanometre. It is named for the 19th-century Swedish physicist Anders Jonas Ångström.

Ανθρώπινο οπτικό σύστημα

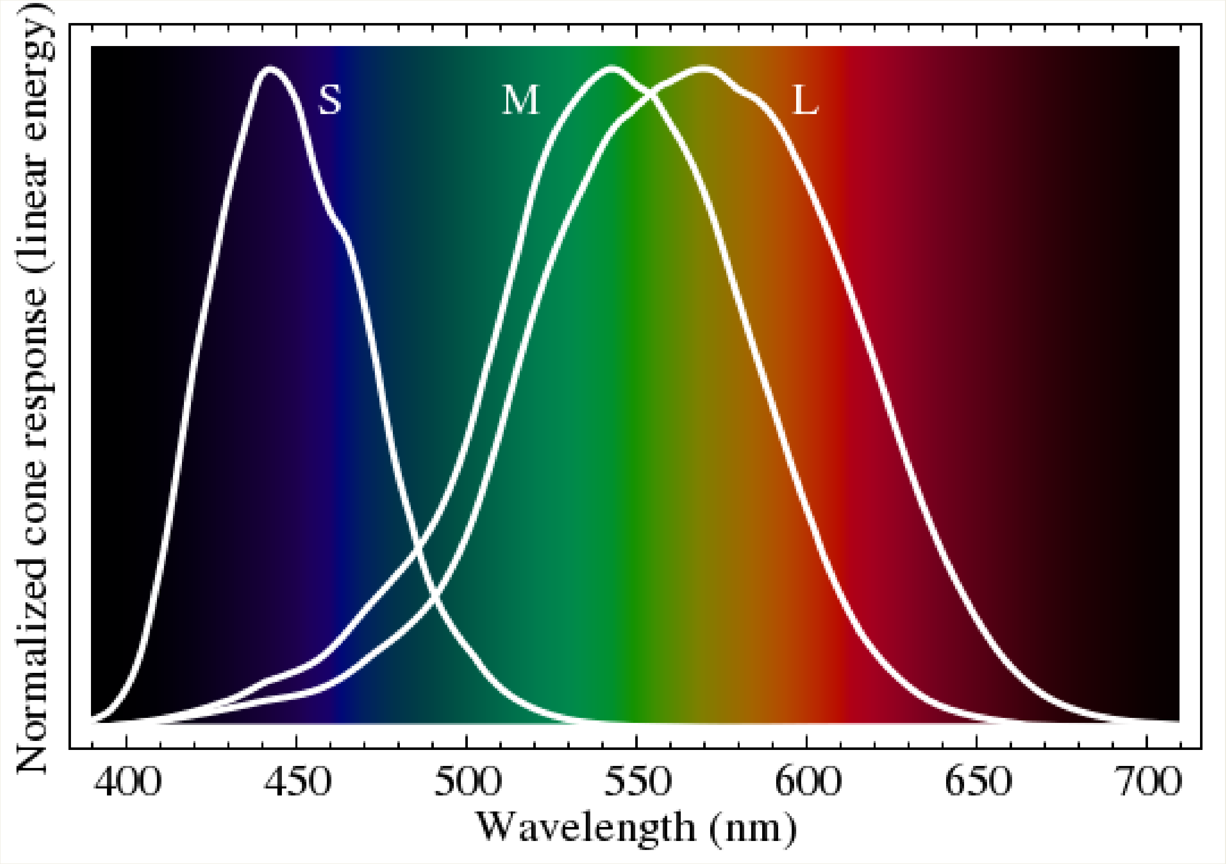


Spectral sensitivities of L, M, S cones as a function of the wavelength λ of the incident radiation.

Cones

- The arrangement of the cones is uneven. Numerically those that respond (are sensitive) to red radiation are much more than those affected by green and those in turn more than those affected by blue radiation.
- **S-cone : M-cone : L-cone = 1:16:32**

Cones

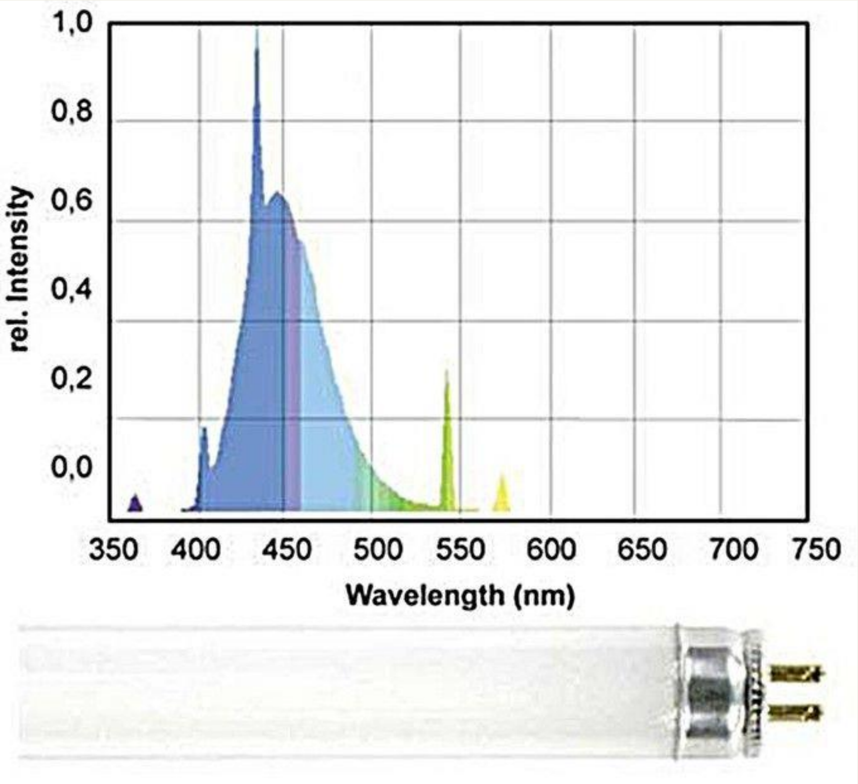


Spectral sensitivities of L, M, S cones as a function of the wavelength λ of the incident radiation.

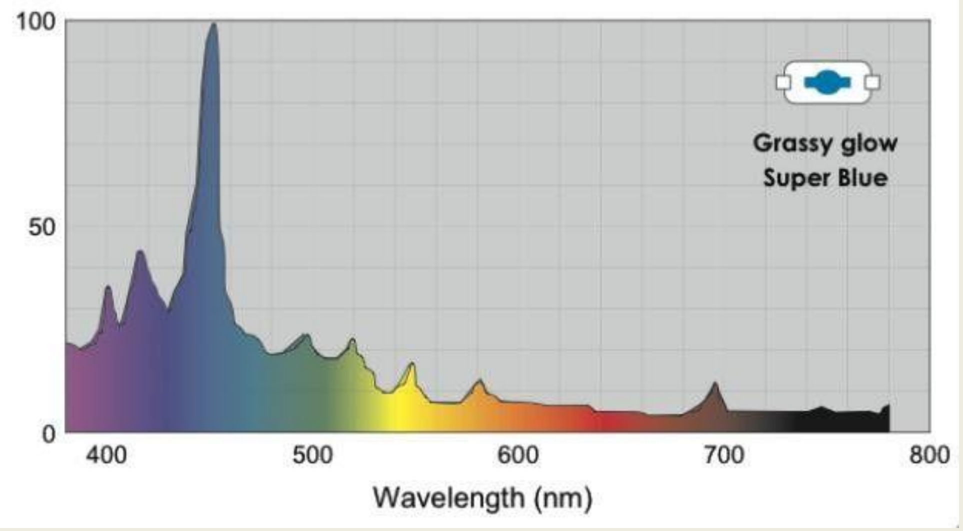
Light source

- **Light sources** emit **electromagnetic radiation** with wavelengths in the **visible spectrum.** The energy of the emitted radiation is distributed, in various wavelengths, which determine the spectrum curve of the light source.
- When the emitted energy is concentrated in a very narrow spectral region around one wavelength we have **monochromatic radiation**, while when it is equally distributed throughout the visible region, we have **white light.**

Light source



Typical Radiant Fluorescent Lamp:
Giesemann Actinic Plus



The spectrum of Grassy glow super blue 25000K

Light source

Characteristics

- **Color temperature (T)**
- **Color Rendering Index (CRI)**

Light source

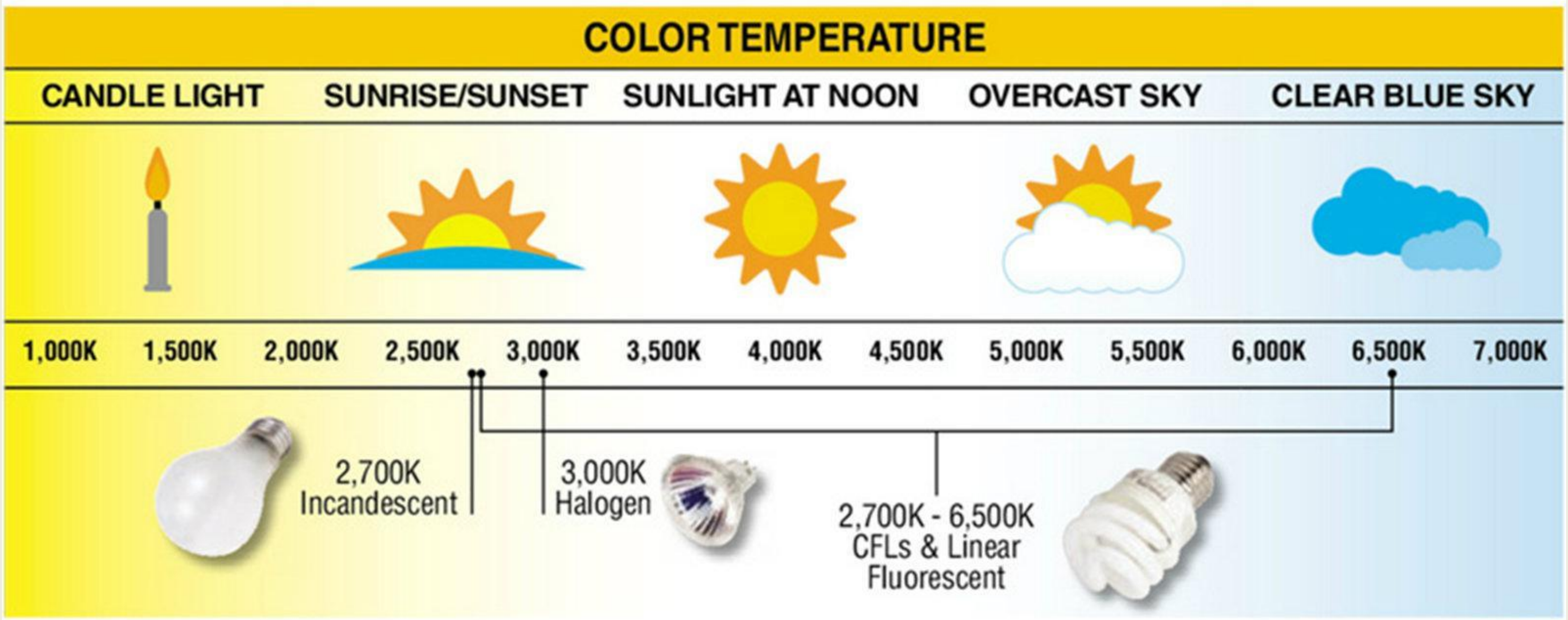
- **Color Temperature (T):**

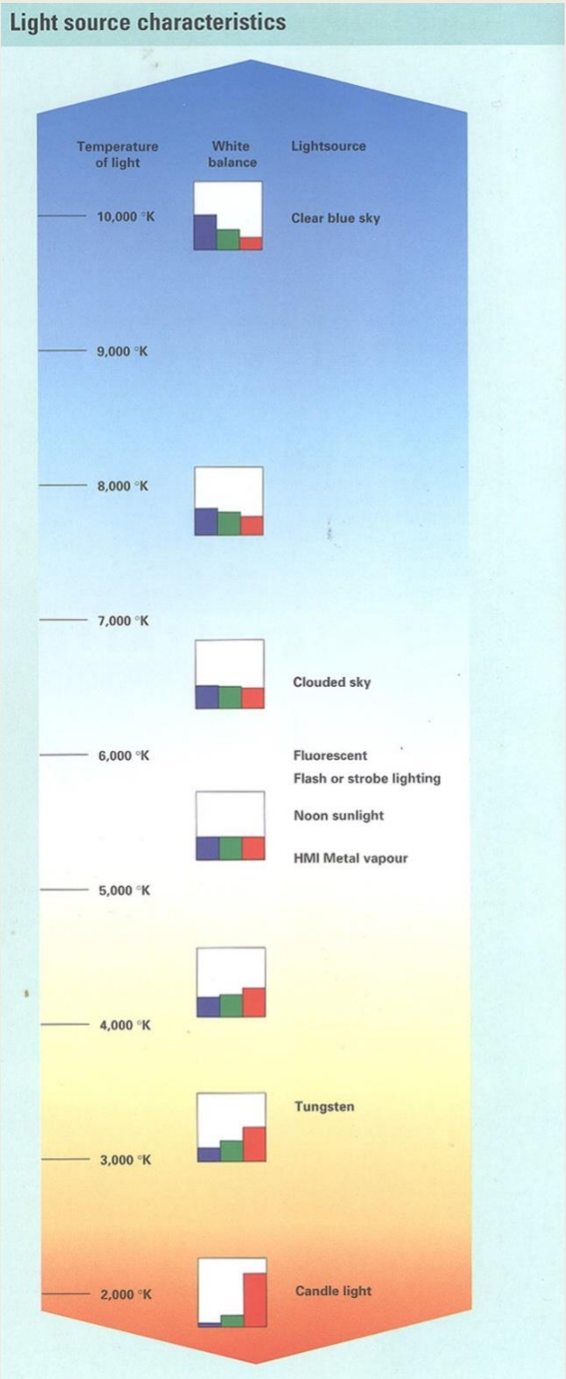
It describes the color of the source light based on the theory of black body radiation.

- **A black body** is a theoretical body that absorbs all the electromagnetic radiation that falls on it (for this reason it is black) and, when heated, emits, according to Planck's law, light of a chromaticity corresponding to the indicated temperature T, measured in degrees Kelvin (K) .
- The **higher the color temperature**, the **cooler the hue** of the light source (lower dominant wavelength).

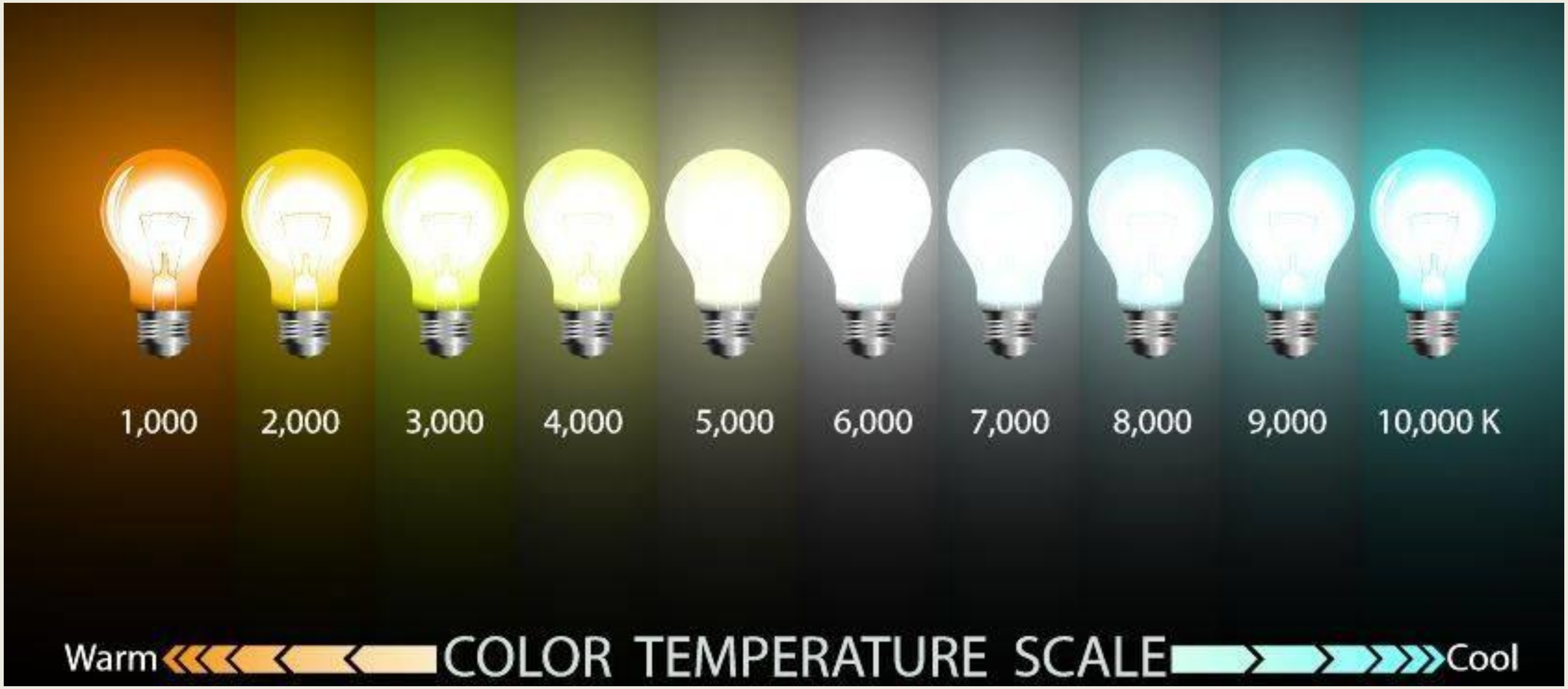
❖ K= C + 273

Color Temperature (T)

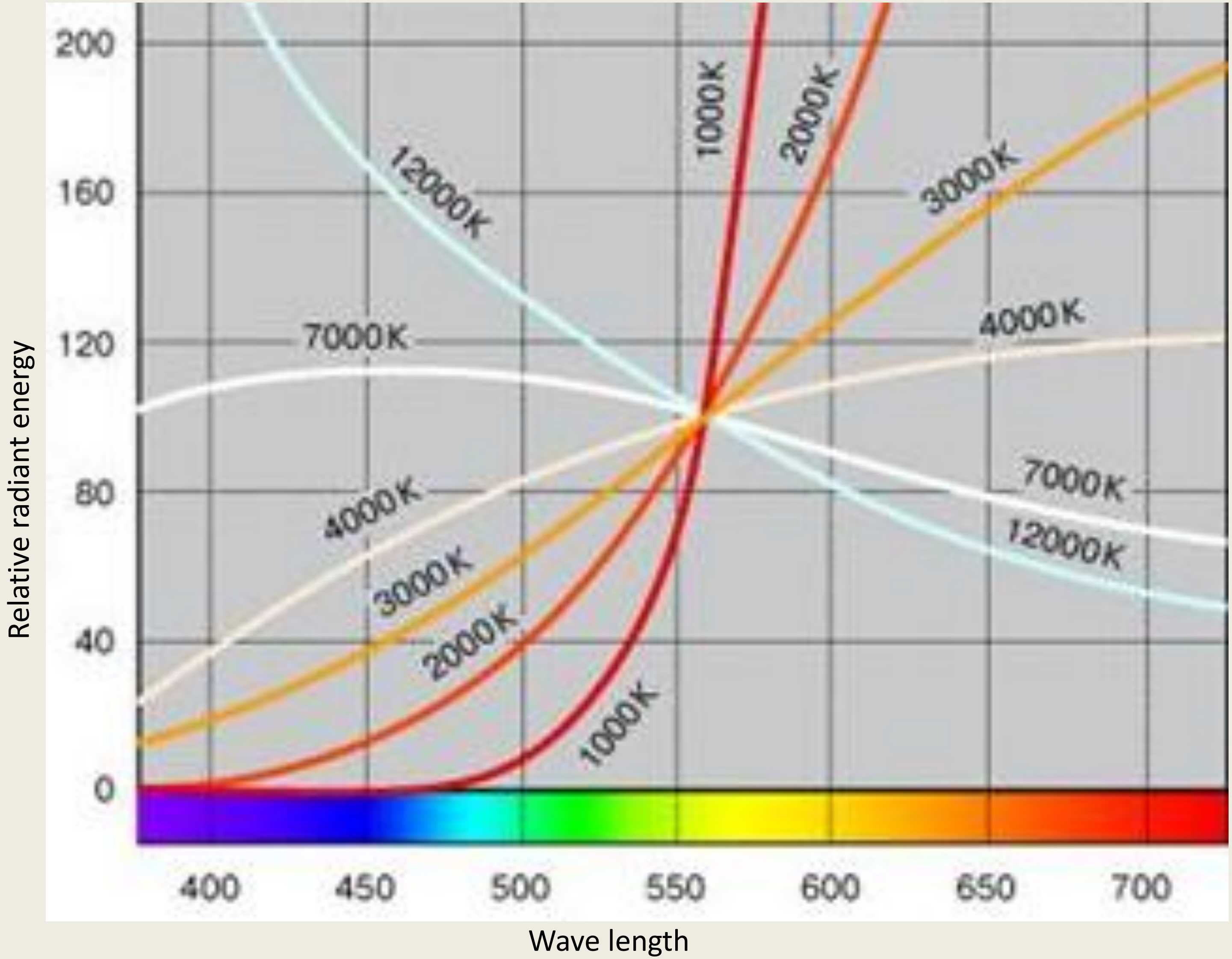



Light source characteristics
Temperature of light
White balance
Lightsource
10,000 °K
Clear blue sky
9,000 °K
8,000 °K
7,000 °K
Clouded sky
6,000 °K
Fluorescent
Flash or strobe lighting
Noon sunlight
HMI Metal vapour
5,000 °K
4,000 °K
Tungsten
3,000 °K
2,000 °K
Candle light

Color Temperature (T)



Color Temperature (T)



Spectral distribution of blackbody radiation as a function of temperature

Color Rendering Index (CRI)

Color Rendering Index (CRI)

- It is used to evaluate the ability to faithfully reproduce the colors of surfaces and objects from the light emitted by a light source, compared to a **reference light source.**
- Calculated: Specified color samples (with CIE 1995 standard), illuminated sequentially by a light source and a reference light source.
- This **difference** is the measure of the **color rendering** of the source under consideration.

Small difference → **big approach** to reference source

Big difference → **significant color deviation**

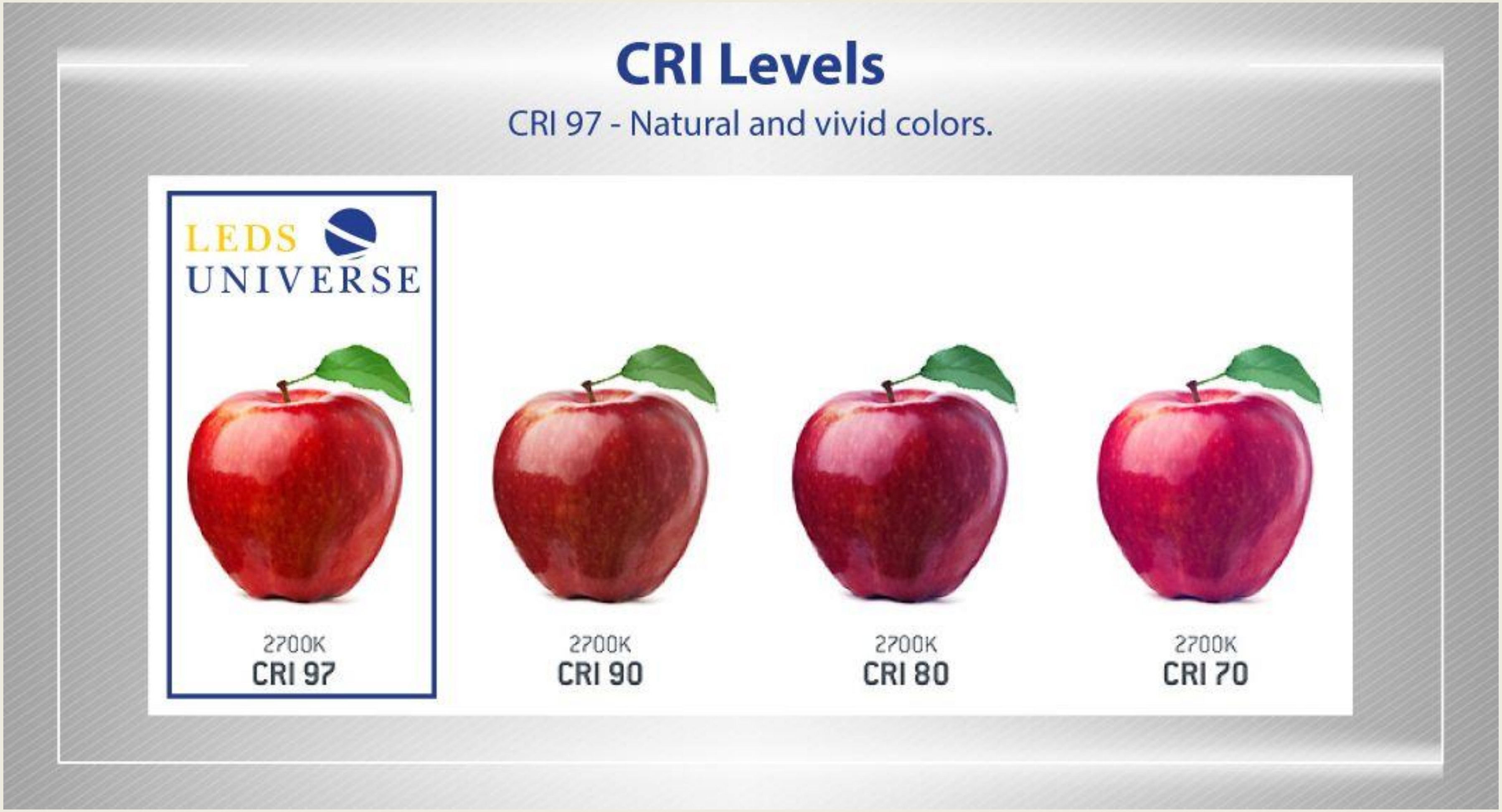
Color Rendering Index (CRI)

Color Rendering Index (CRI)

- **CRI:** numeric values from **0-100**
- **CRI 100**: **White light** with the same characteristics **as daylight.**
- **CRI greater than 95: Incandescent** lamps
- **Halogen lamps:** They emit more in the red / yellow part of the visible spectrum.

  They have a **continuous spectrum just like daylight:** important factor in the response of the human eye to light.
- **CRI 90 - 100:** Some of the **fluorescent** lamps.

Color Rendering Index (CRI)



Color Rendering Index (CRI)

Lamps that deliver natural color

- **PHILIPS**

  Graphica Pro TLD 90

  58W/950

  (5300 Kelvin)   CRI ∼ 98

- **OSRAM**

  ColorProof L-58W/950

  (5400 Kelvin))   CRI ∼ 98

or even

- **OSRAM**

  Lumilux De Lux L58W/954

  (5400 Kelvin)   CRI > 90

Ugra Light Indicator

This is how the light indicator appears under standard light of 5000 K. All patches show the same color.

If the light indicator is viewed under a non-standard light source. The patches show different colors.

Light source

Classification of light sources

- **Black body**
- **Daylight**
- **Light sources of artificial lighting**

- Incandescent lamps
- Gas discharge lamps: They consist of a tube containing a gas (hydrogen vapor or xenon gas) and are excited by electricity. **Fluorescent lamps** are the most common type of such lamps. Phosphors lining the inside of the tube absorb the photons emitted by the gas and re-emit them at different wavelengths.
- LEDs

* A black body or blackbody is an idealized physical body that absorbs all incident electromagnetic radiation, regardless of frequency or angle of incidence.

Light source

Standardization of light sources according to CIE

- **Light source A :** Simulates the light **of incandescent lamps** T: 2,855.5K

With the help of filters that change the spectral energy distribution of source A, sources B and C were obtained

- **Light source B:** Corresponds to the radiation emitted by **sunlight** (sunlight at midday) T: 4874K

- **Light source C:** Simulation of **morning** sunlight T: 6774 K

Standard lighting sources are not natural sources, but lighting models (standards) with a discrete spectral energy distribution.

Light source

- **Light source D**: Series of lamps with a variety of models corresponding to **daylight** (**D**aylight)
- D50: T= 5,000 K (Graphic Arts)
- D55: Photography
- D65: T= 6500 K (No longer supported)
- **D50** is widely used in **graphic arts.**
- **Light source E:** Ideal (non-existent) light source, used for calculations only. It emits **equal energy** at **all wavelengths** of the visible spectrum.
- **Light source F:** Represents characteristic wavelengths from a wide variety of **fluorescent lamps,** such as F2, F3, to F12.

Standard Observer

In addition to defining standard illuminants, the CIE conducted experiments to quantify the **standard observer.** The development of the standard observer is the basis for all instrumental color measurement.

A standard observer is defined as a typical human observer with normal color vision.

An important element is the observation conditions that vary between the visual angle fields **2° (1931)** and **10° (1964)** and give different results characterized by the sensitive field of color discrimination of the **2°** angle and the objective and more complete observation of the **10°** angle.

Standard Observer

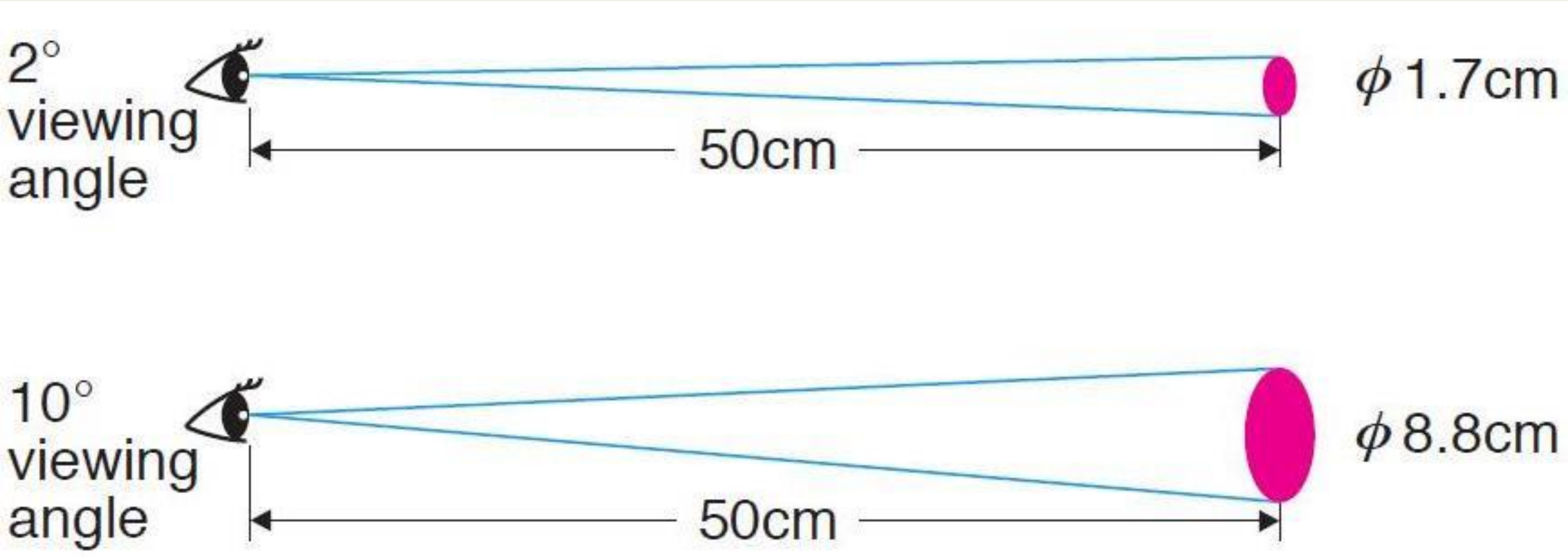
- **1931 Standard Observer (2-degree observer).**

- In 1927, physicists John Guild and David Wright gathered subjects and performed a color matching experiment to determine how the average person perceives color. Subjects were asked to look through a hole and match each color in the spectrum by combining various intensities of red, green, and blue lights. The hole only allowed a 2-degree field of view because of the belief that our color-sensing cones were located in a 2-degree arc in the fovea, a region of the retina.
- Based on the responses in this experiment, values were plotted to reflect how the average human eye senses the colors in the spectrum with a 2-degree field of view. Each curve – bar x, bar y, and bar z – represents one of the three primary colors of light. Referred to as the 2 Degree Standard Observer, CIE published this as a mathematical function in 1931 to be used in the quantification of color and standardize the way color is evaluated.

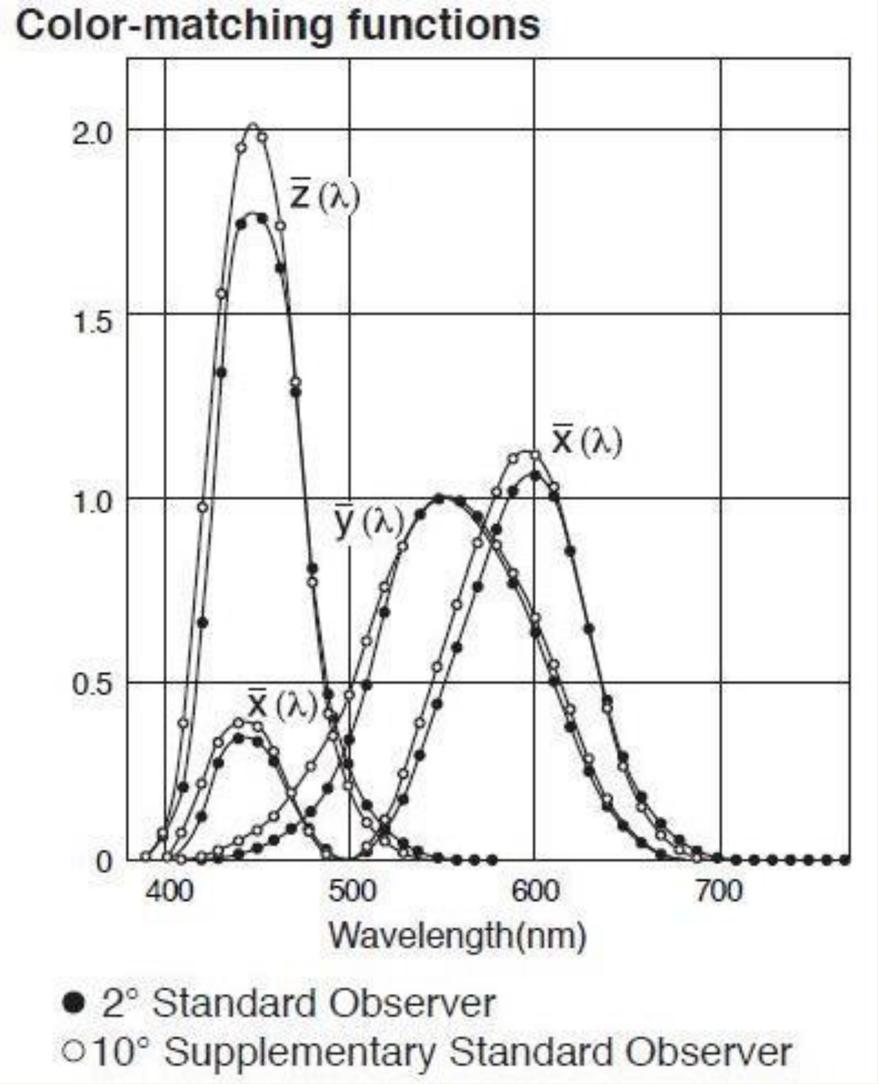
Standard Observer

- **1964 Observer (10 Degree Observer)**
- It was later determined that color values calculated using the 2-degree observer do not always correlate well with visual assessment, since most visual assessments are done with a field of view greater than 2 degrees.
- In 1964, the CIE defined a supplemental observer to provide better correlation with commercial color matching. The supplemental observer is based on color matching experiments which were conducted using a 10-degree field of view.
- Repeatability of the standard observer was found to be more accurate using a larger field of view. Today, the 10-degree observer is most widely used in color formulation and color quality control.

Standard Observer



Standard Observer



Object

- There are three possibilities for light rays striking a surface:
- **reflection R(λ)**
- **propagation T(λ)** and
- **absorption A(λ)**
- The color of an object that we finally perceive, is determined by the spectral distribution of the incident light, which reaches our eye differentiated after reflection on the surface of the object.
- The percentage that will be reflected is a function of the shape of the **material surface**, the **nature of the material**, the **wavelength**, the **geometry of the illumination** and the **observation.**