Electromagnetic properties of Foods

Content:

-Electromagnetic spectrum
-Food color

How and where can we use electromagnetic spectrum in food science?

- For heating: reheating, precooking, baking, drying, pasteurization, sterilization
- For quality analyses of foods: color measurement, composition analyses

INTERACTION OF OBJECTS WITH LIGHT

When electromagnetic radiation strikes an object, the resulting interaction is affected by the properties of an object such as

- color,
- physical damage, and
- presence of foreign material on the surface.

Electromagnetic radiation is transmitted in the form of waves and it can be classified according to wavelength and frequency.

-Radiowaves

-Microwaves

-Infrared

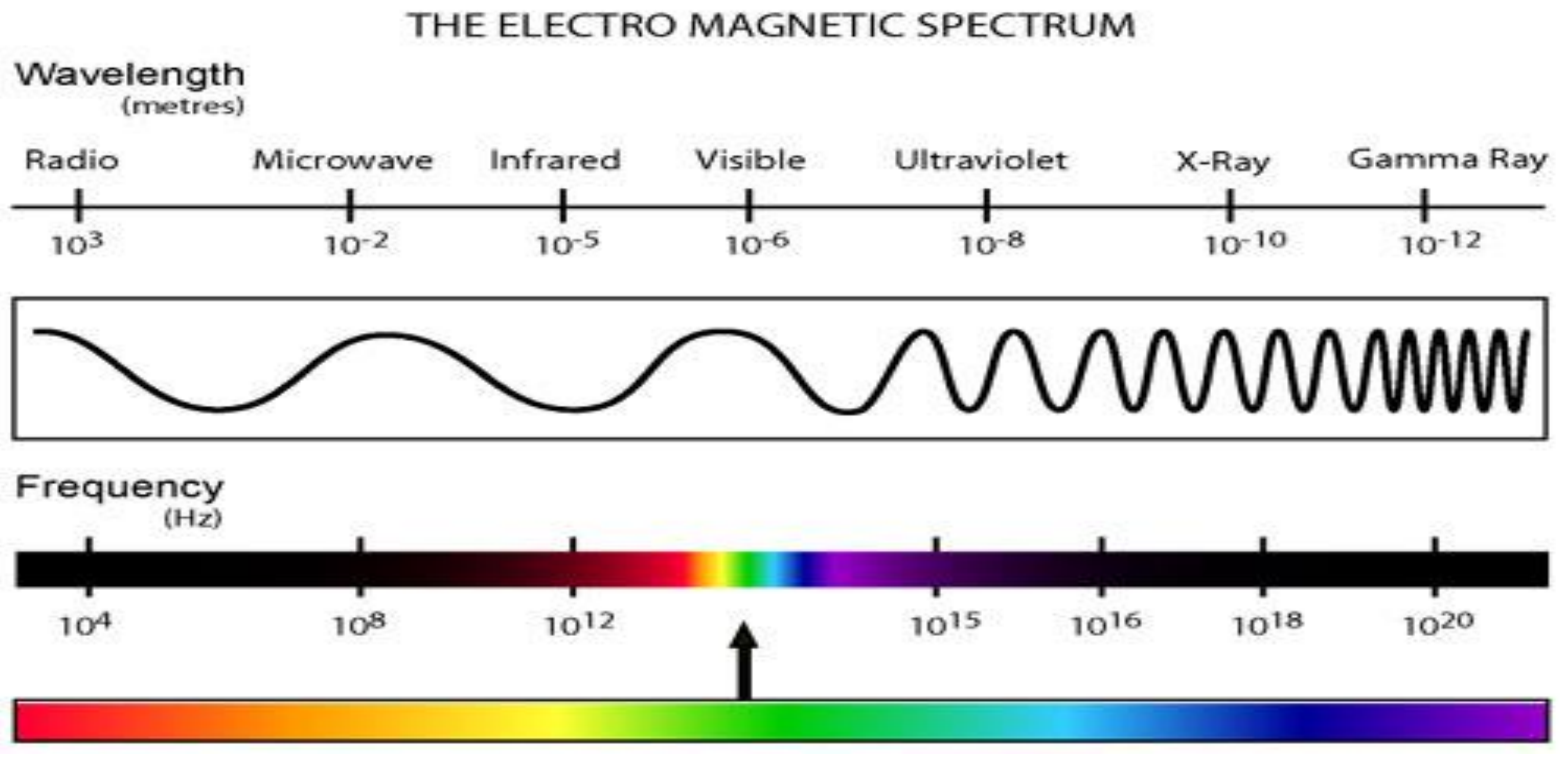
-Visible light

-Ultraviolet

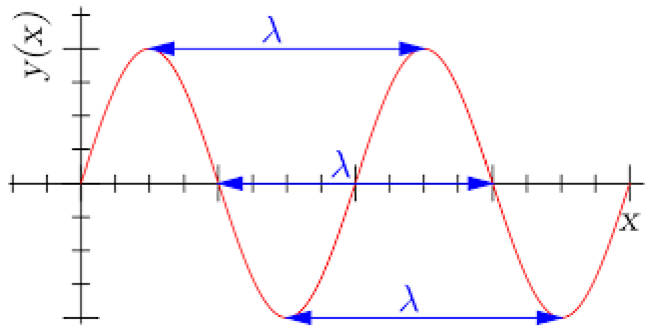
-X-rays

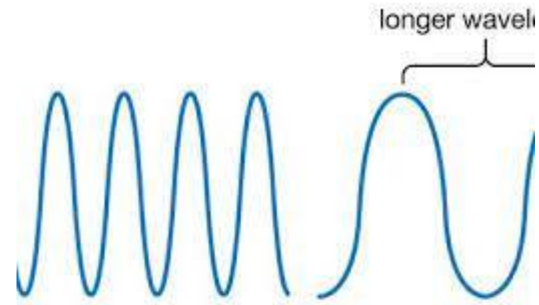
-Gamma-rays

Electromagnetic Spectrum

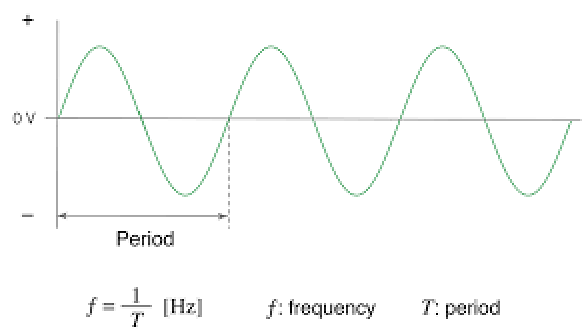


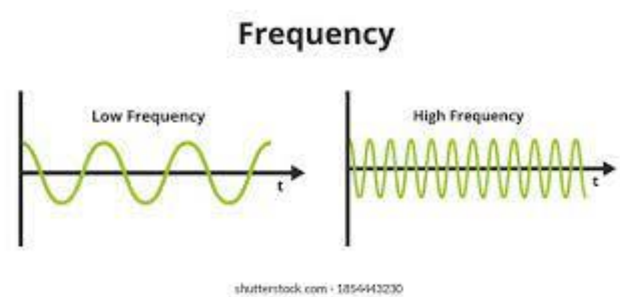
- ***Wavelength*** is defined on the left below, as the distance between adjacent peaks (or troughs), and may be designated in meters, centimeters or nanometers (10^{-9} meters).



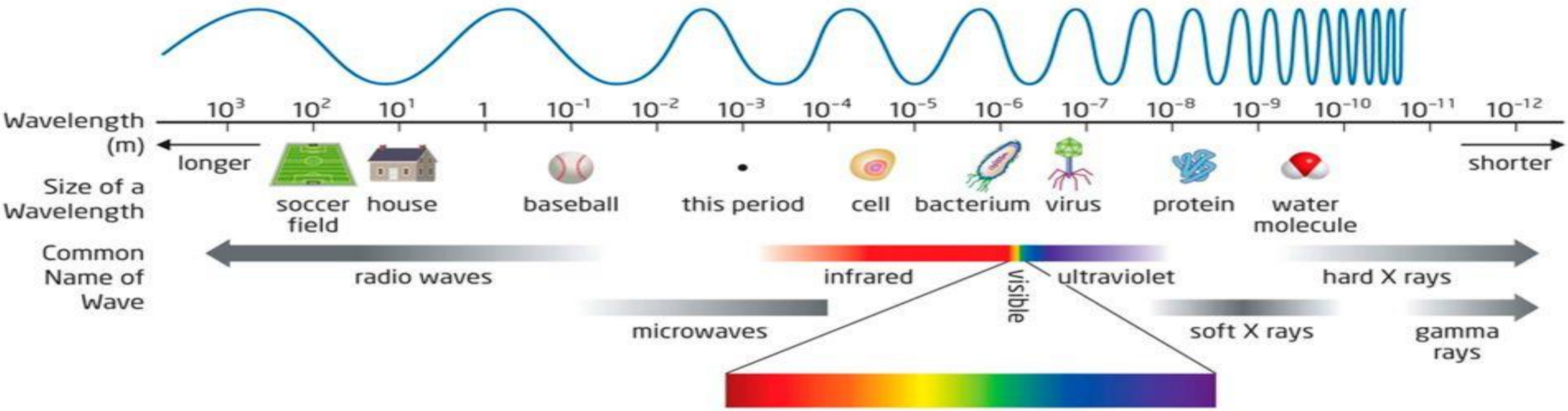


- ***Frequency*** is the number of wave cycles that travel past a fixed point per unit of time, and is usually given in cycles per second, or hertz (Hz).



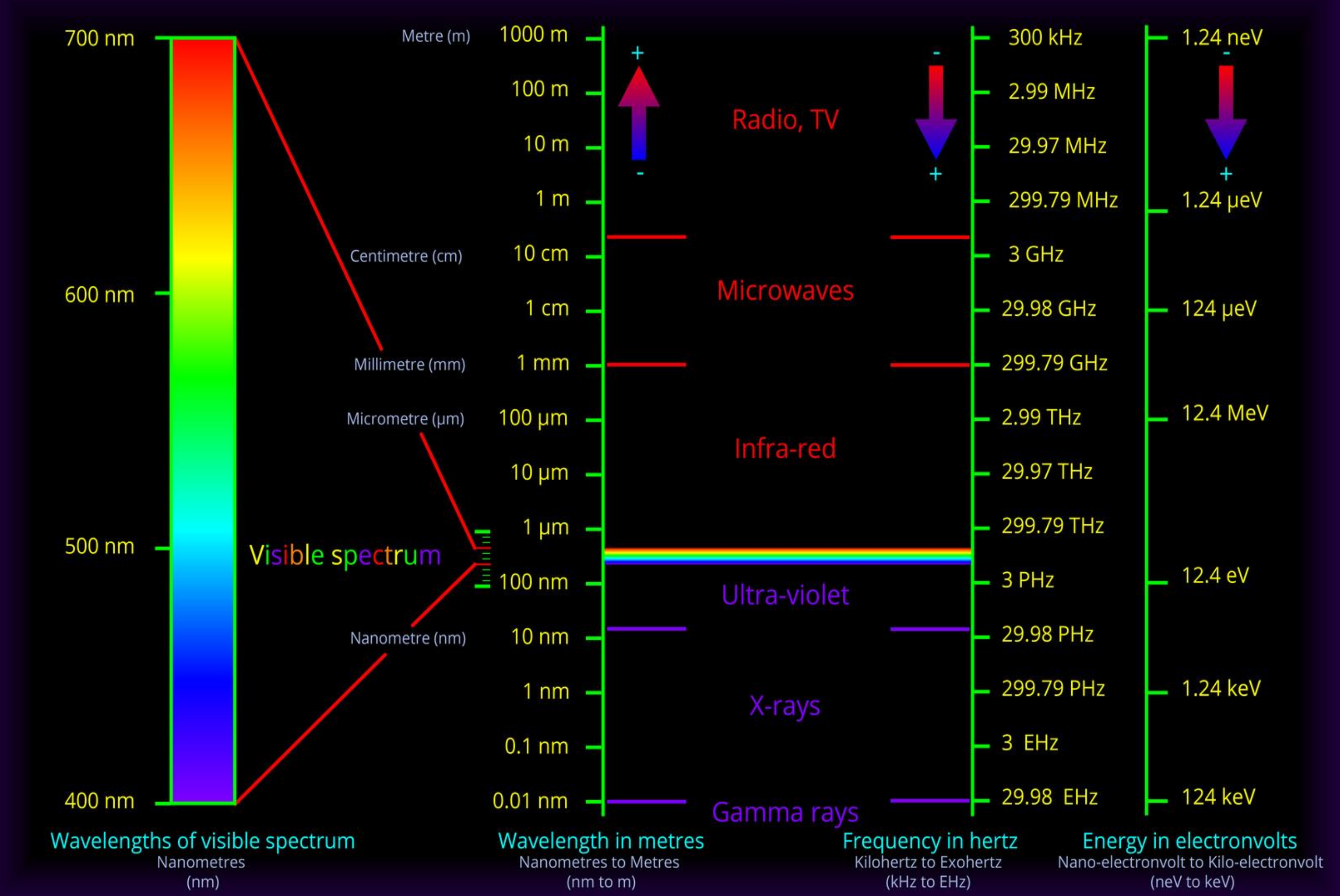


Electromagnetic Spectrum

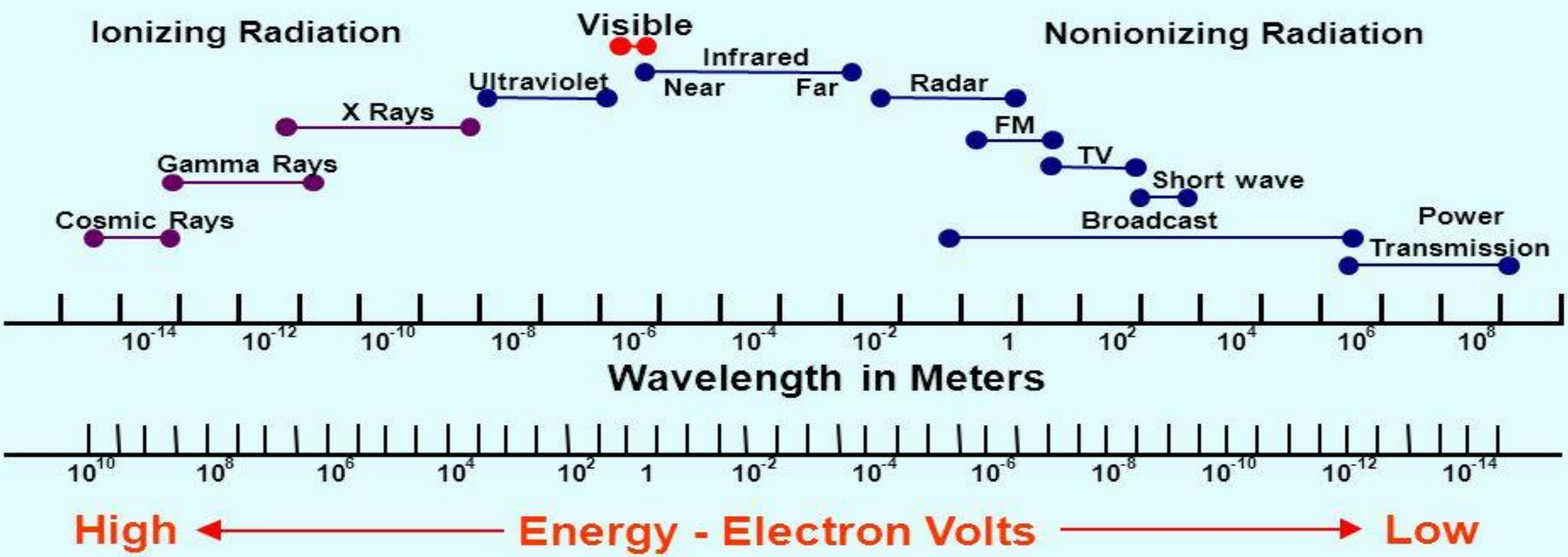


Radio waves
have the longest wavelenghts and the lowest frequencies of all the electromagnetic waves
Gamma rays
have the shortest wavelengts and the highest frequencies of all the electromagnetic waves

Electromagnetic Spectrum



Electromagnetic Spectrum



- Electromagnetic waves travel at the speed of light and are characterized by their frequency (f) and wavelength (λ).

$$c = \lambda f$$

where

c: the speed of light in vacuum (3.0×10^8 m/s).

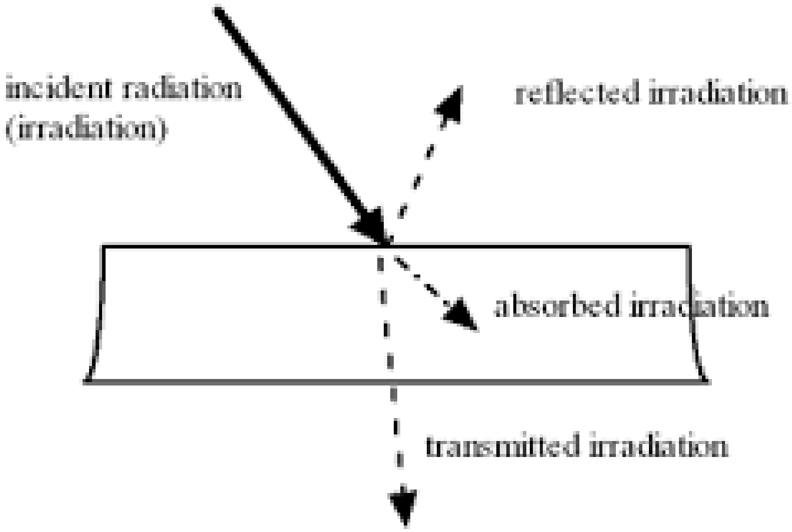
- Radiation can exhibit properties of both waves and particles.
- Visible light acts as if it is carried in discrete units called photons.
- Each photon has an energy, E, that can be calculated by:

$$E = h f$$

where

h: Planck's constant (6.626×10^{-34} J·s).

- When radiation of a specific wavelength strikes an object, it may be reflected, transmitted, or absorbed.

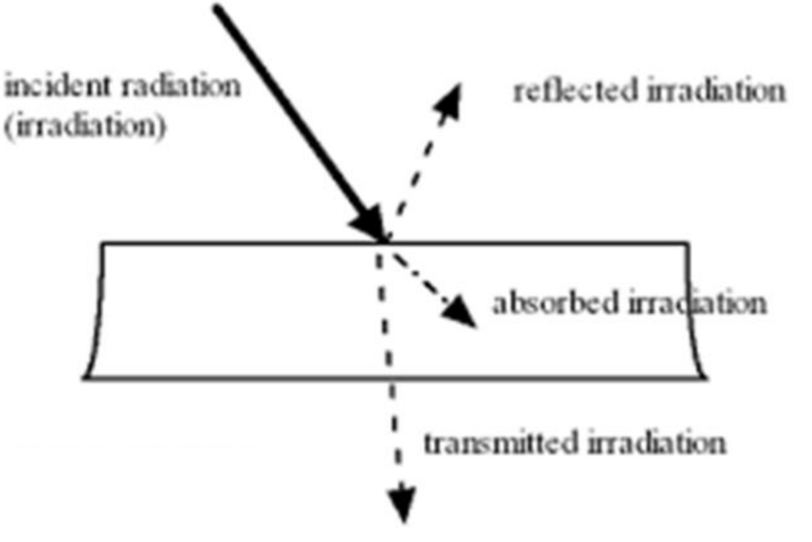


The relative proportion of these types of radiation determines the appearance of the object. A material is said to be transparent when the light impinging on it passes through with a minimum reflection and absorption. The opposite of transparency is opacity.

That is, an object that does not allow any transmission of light but absorbs and/or reflects all the light striking is termed opaque.

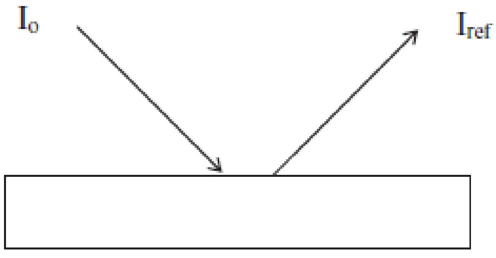
In opaque surfaces, certain specific wavelengths of light are absorbed and the others are reflected.

As a result, color is formed. If all the visible light is absorbed, the object appears black. If both reflection and transmission occur, the material is said to be translucent.



- If the I_0 is the radiant energy striking the object and I_{ref} is the amount of energy reflected from the object, the total reflectance R is defined as:

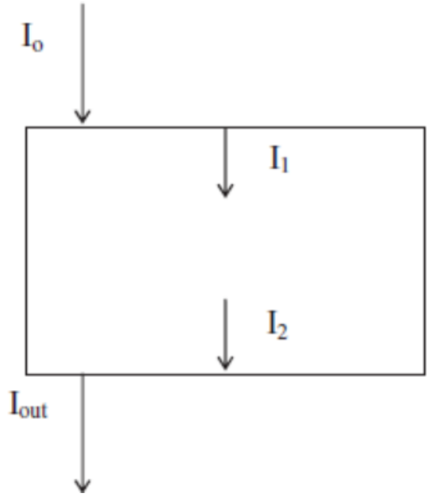
$$R = I_{ref}/I_0$$



Reflection

- If I_0 is the incident energy, I_1 is the energy entering the object, I_2 is the energy striking the opposite face after transmission, and I_{out} is the energy leaving the opposite phase, transmittance (T) and absorbance (A) are defined as:

$$T = I_{out}/I_0$$
$$A = log(I_1/I_2)$$



Transmission

Optical density (OD) is a measure of the relative amount of incident energy transmitted through the object.

$$OD = log\ (I_0/I_{out}) = log\ (1/T)$$

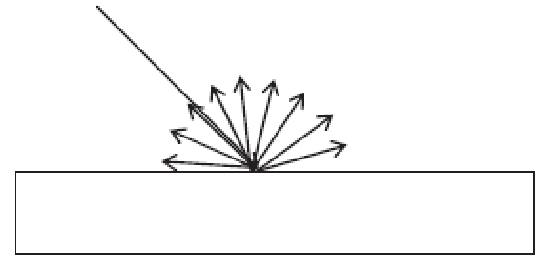
There are two types of reflection:

- Diffuse reflection
- Specular reflection.

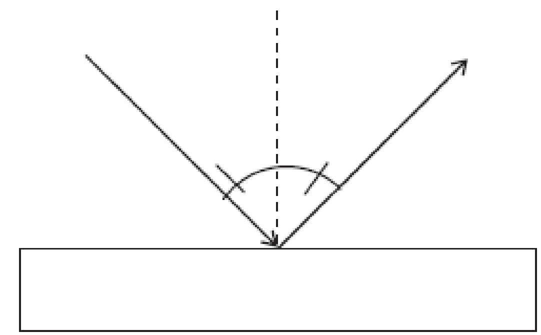
In diffuse reflection, radiation is reflected equally in all directions. When a surface is rough, the incident light will bounce around and will rise to a greater amount of diffuse light. Opaque surfaces reflect light diffusely.

Specular reflection is highly directional instead of diffuse. The angle of reflection is equal to the angle of incidence of the radiation beam.

It is mainly responsible for gloss or shiny (mirror-like) appearance of the materials.

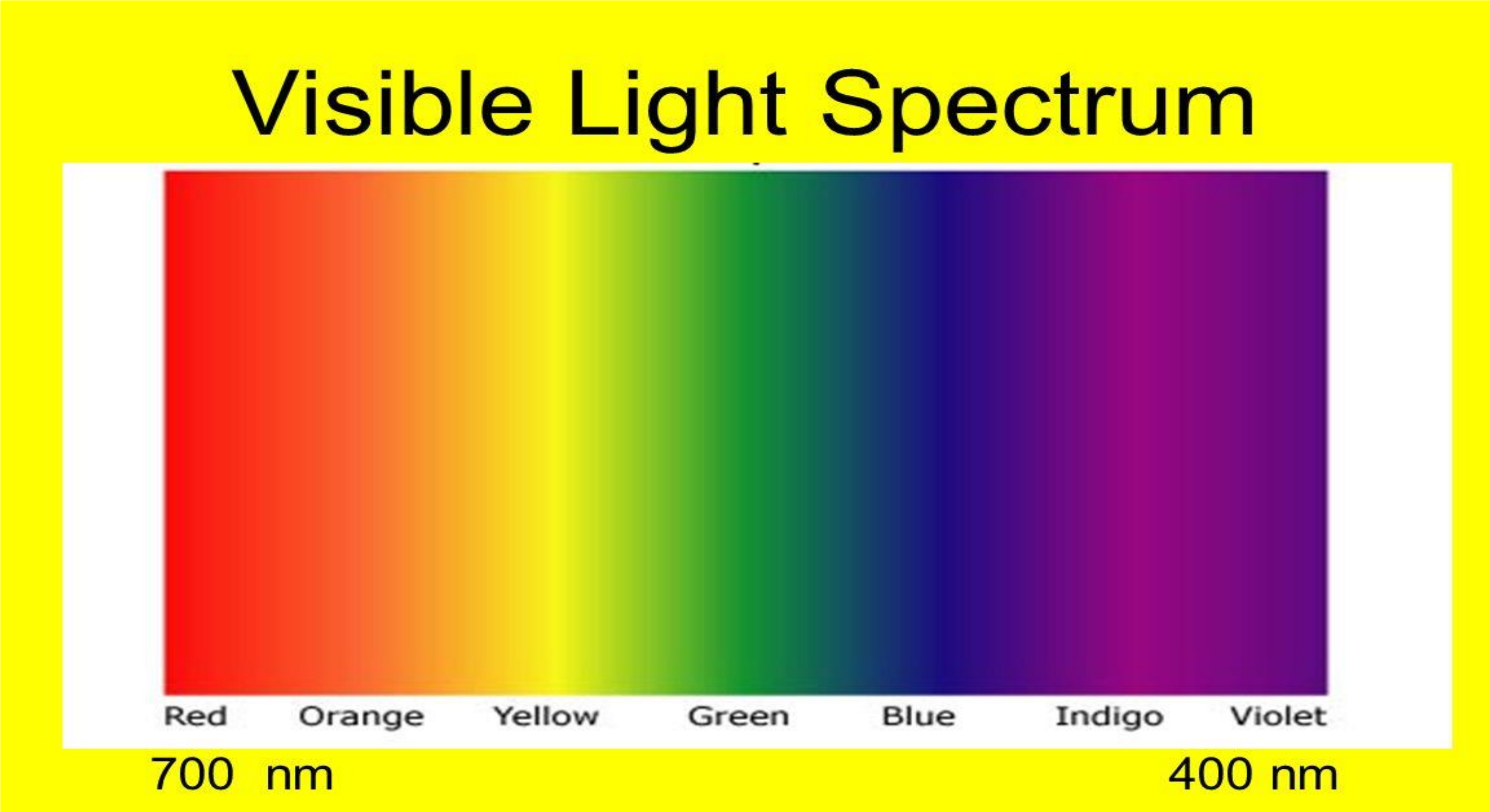


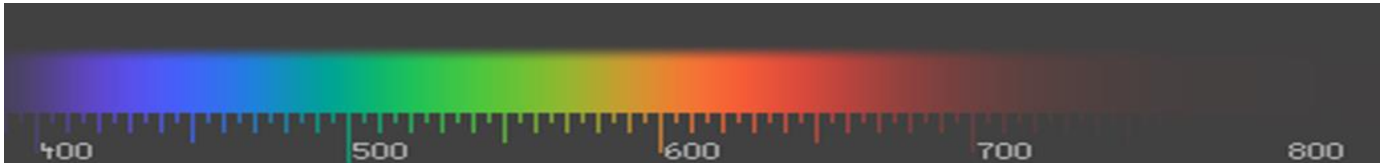
Diffuse reflection



Specular reflection

Visible light spectrum and color





Color	Wavelenght range	Frequency range
Red	~ 620-780 nm	~ 430-480 THz
Orange	~ 585-620 nm	~ 480-510 THz
Yellow	~ 570-585 nm	~ 510-540 THz
Green	~ 490-570 nm	~ 540-610 THz
Blue	~ 440-490 nm	~ 610-670 THz
Indigo	~ 420-440 nm	~ 670-750 THz
Violet	~ 400-420 nm	~ 750–780

The measurement of color

- If all wavelengths reach our eyes at the same time, we perceive it as white, and if no light reaches our eyes, we perceive it as black.
- The human eye: detect wavelengths between 380nm and 780nm, so this part of the electromagnetic spectrum is called visible light.

- The measurement of color is known as colorimetry.

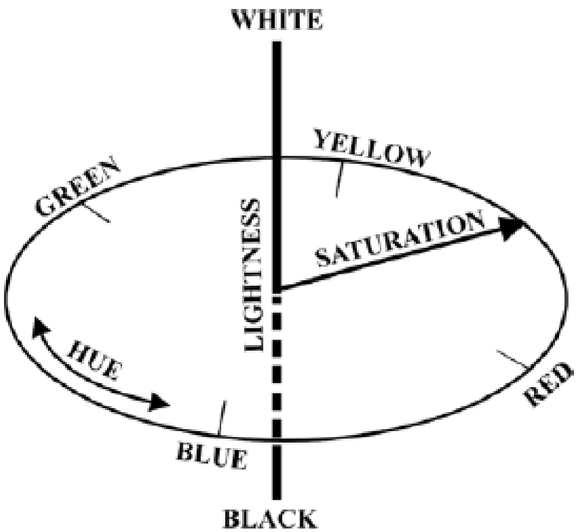
A variety of instruments are used in this field.

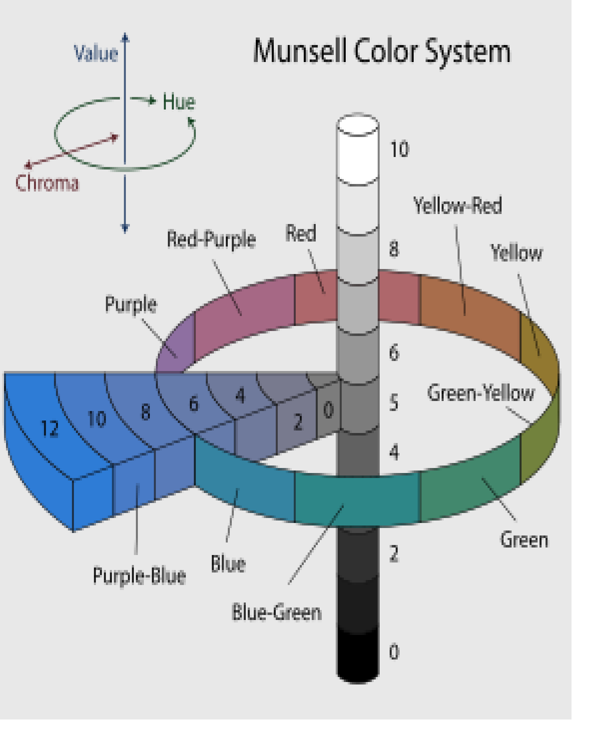
- Colorimeters
- Spectrophotometers

Munsell color system

The Munsell color system is a color space that specifies colors based on three properties of color:

- hue (basic color),
- chroma (color intensity), and
- value (lightness).



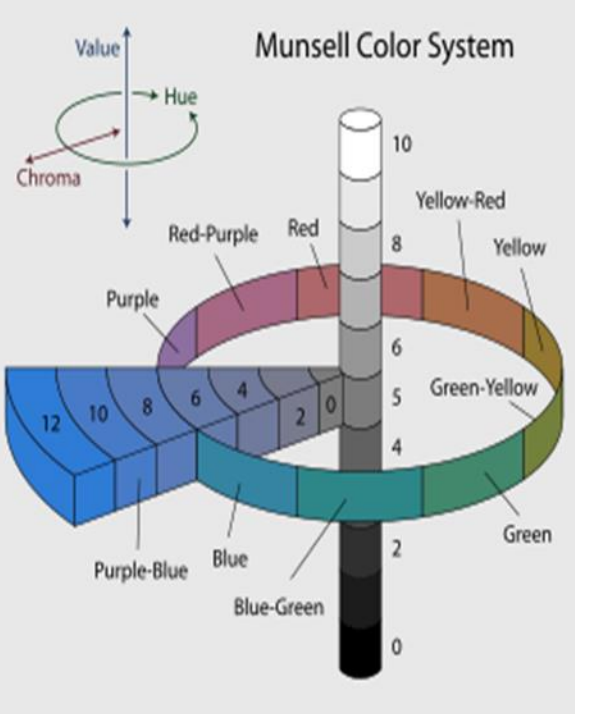


Three-dimensional Munsell color system

Munsell color system

The system consists of three independent properties of color which can be represented cylindrically in three dimensions as an irregular color solid:

- hue, measured by degrees around horizontal circles
- chroma, measured radially outward from the neutral (gray) vertical axis
- value, measured vertically on the core cylinder from 0 (black) to 10 (white)



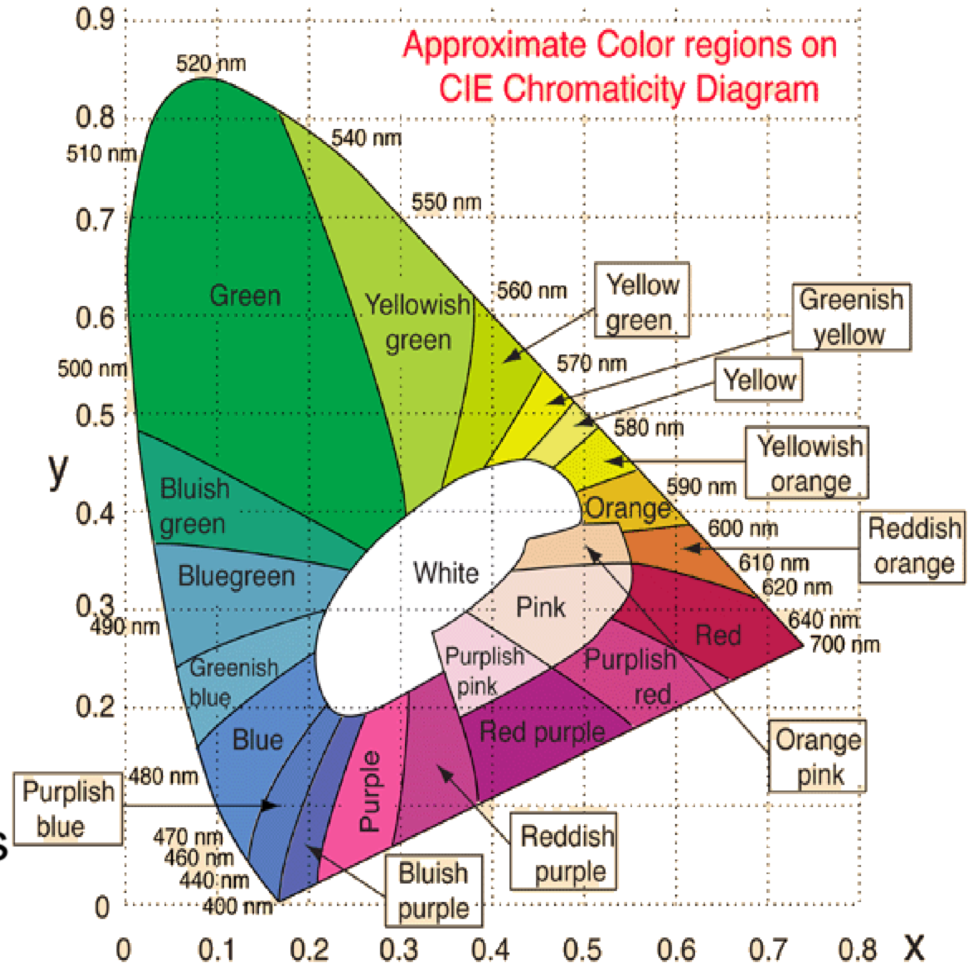
CIE (the Commission Internationale d'Éclairage) Color System

- One of the well known systems to describe colors is the CIE color system developed by the International Commission on Illumination in 1931.
- This is a trichromatic system, that is, any color can be matched by a suitable mix of the three primary colors—red, green, and blue which are represented by X, Y , and Z, respectively.
- This system uses the chromaticity diagram to designate various colors.
- When determining the specification for a color, the reflectance and transmittance at each wavelength are measured.
- These values are weighted by functions that represent the relative intensities of reflectance at various wavelengths which would be perceived as blue, green, and red by a standard observer.
- The application of the weighting to a reflectance curve gives the tristimulus values, which are denoted by the capital letters X, Y , and Z.

CIE Color System

- These values are then used to calculate the chromaticity coordinates, designated by lowercase letters x (red), y (green), and z (blue). The value for x can be calculated by:

$$x = \frac{X}{X+Y+Z}$$

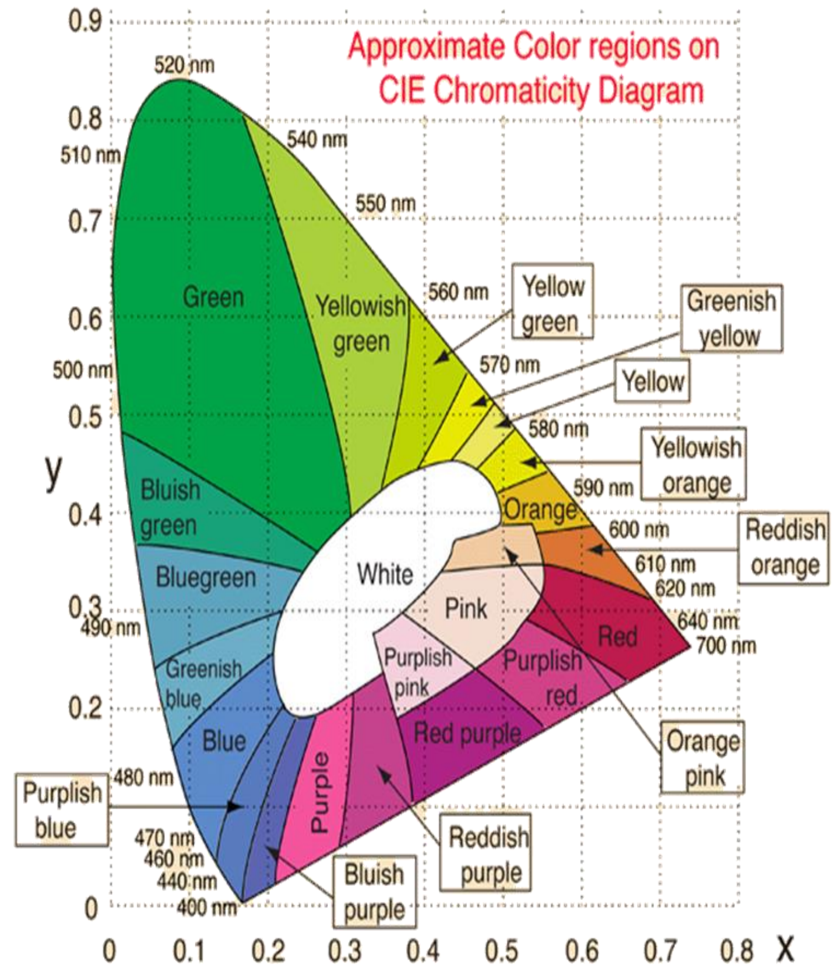


The values for y and z can be calculated by replacing X with Y and Z, respectively, in the numerator. Since the sum of the chromaticity coordinates (x, y, and z) is always unity, the values x and y alone can be used to describe

a color.

CIE Color System

- When x and y are plotted, a chromaticity diagram is obtained (Fig).
- The third dimension of lightness is defined by the Y tristimulus value.
- Color is defined by its chromaticity coordinates x and y and its lightness, the tristimulus Y value.
- All real colors lie within the horseshoeshaped locus marked with the wavelengths of the spectrum colors.
- The color is read from the diagram.
- Once the point has been located on the diagram, the hue (dominant wavelength) and the purity (percent saturation) of the color are determined.



*CIE L*a*b** (CIELAB) Color Spaces

- developed in 1976 and offers more advantages over the system developed in 1931. It is more uniform and based on more useful and accepted colors describing a theory of opposing colors.
- The location of any color in the CIELAB color space is determined by its color coordinates: *L*,a**, and *b**.

***L** represents:*

the difference between light (*L** = 100) and dark (L* = 0).

The component *a represents:**

the difference between green (−*a**) and red (+*a**) and

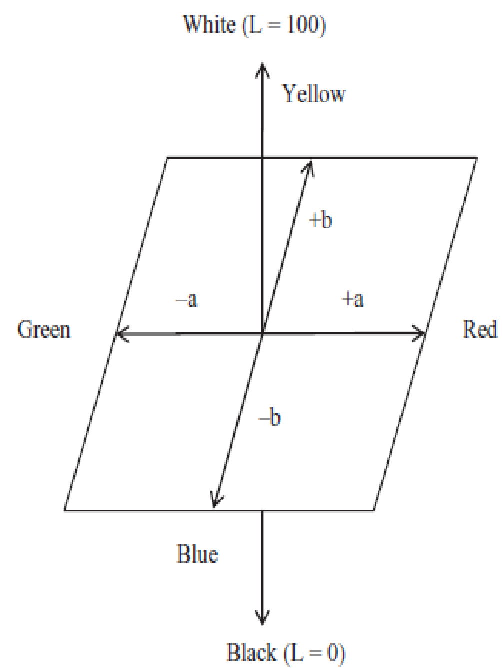
The component *b represents:**

the difference between blue (−b∗) and yellow (+b∗).

- If *the L∗, a∗,* and *b∗* coordinates are known, then the color is not only described, but also located in the space.

Hunter *L,a,b* Color Space

- This system is based on *L, a*, and *b* measurements.
- The *L* value represents lightness and changes from 0 (black) to 100 (white).
- The *a* value changes from −*a* (greenness) to +*a* (redness),
- *The b* value is from −*b* (blueness) to +*b* (yellowness).
- Like the CIE system, the Hunter scale is also derived from X, Y , Z values.
- The dimensions of the Hunter L, a, b system are shown in Fig.
- The Hunter L (lightness) values are directly comparable to the Y of the CIE system or value of the Munsell system. Determining a and b values provides information equivalent to that of determining the hue and chroma dimensions of the Munsell system.



Hunter L, a, b color system

Lovibond System

- In the CIE system, X, Y , and Z are added in certain proportions to match a given color.
- The Lovibond scale is based on the opposite principle. It starts with white and then by the use of red, yellow, and blue filters, colors are subtracted from the original white to achieve the desired match with the sample.

Lovibond tintometer is used:

- In beer industry
- Oil industry
- Honey industry

Lovibond system

- The instrument has a set of permanent glass color filters in the three primary colors: red, yellow, and blue.
- The sample is placed in a glass cell and the filters are introduced into the optical system until a color match is obtained under specified conditions of illumination and viewing.
- The color of the sample is measured with transmitted light.
- The Lovibond measurements of different colors are given in Table:

Color	Lovibond measurement
Light yellow	2.0-3.0
Medium yellow	3.0-4.5
Deep straw/gold	4.5-6.0
Deep gold	6.0-7.5
Light amber	7.5-9.0
Copper	9-11
Red brown	11-14
Light brown	14-17
Medium brown	17-20
Light black	20-25
Black	>25

Color differences

- CIE $L*a*b*$ (CIELAB) total color difference ($\Delta E*$) is the distance between the color locations in CIE space.
- This distance can be expressed as:

$$\Delta E* = [(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2]^{1/2}$$

Where:

$\Delta L*$ is the lightness difference:

$L*_{sample} - L*_{standard}$

$\Delta a*$ is the red/green difference:

$a*_{sample} - a*_{standard}$

$\Delta b*$ is the yellow/blue difference:

$b*_{sample} - b*_{standard}$

Color differences

- ΔE^* is an equally weighted combination of the coordinate (L^*, a^*, b^*) differences.
- It represents the magnitude of the difference in color but does not indicate the direction of the color difference.
- Color difference can also be described specifying L^*, C^*, and h^* coordinates as:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta C^*)^2 + (\Delta H^*)^2]^{1/2}$$

The chroma difference between sample and standard is given as:

$$\Delta C^* = C^*_{sample} - C^*_{standard}$$

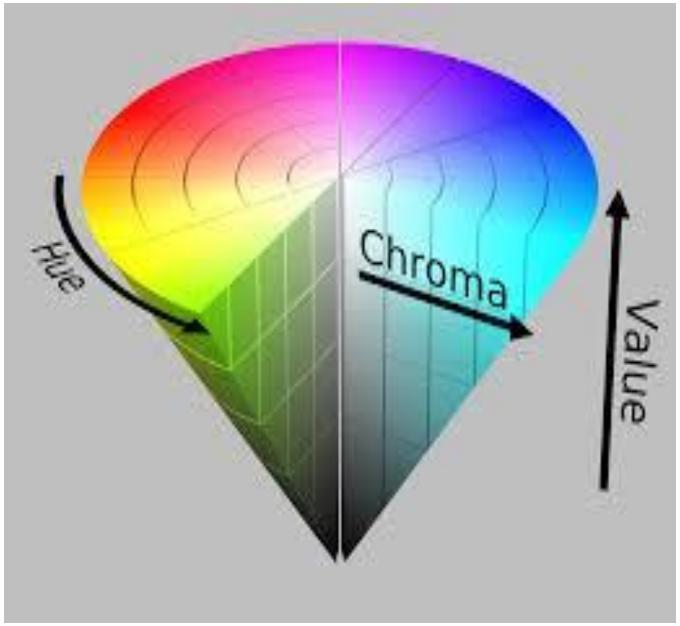
The metric hue difference, ΔH^*, is not calculated by subtracting hue angles. It is expressed as:

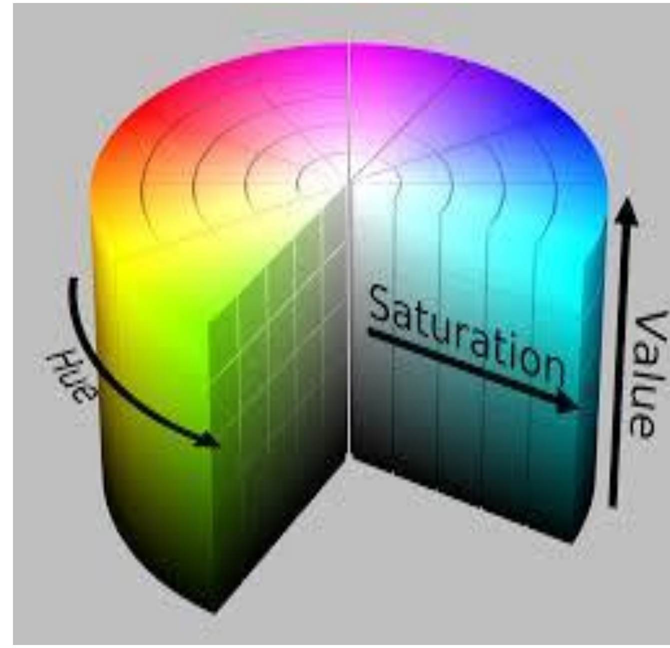
$$\Delta H^* = [(\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta C^*)^2]^{1/2}$$

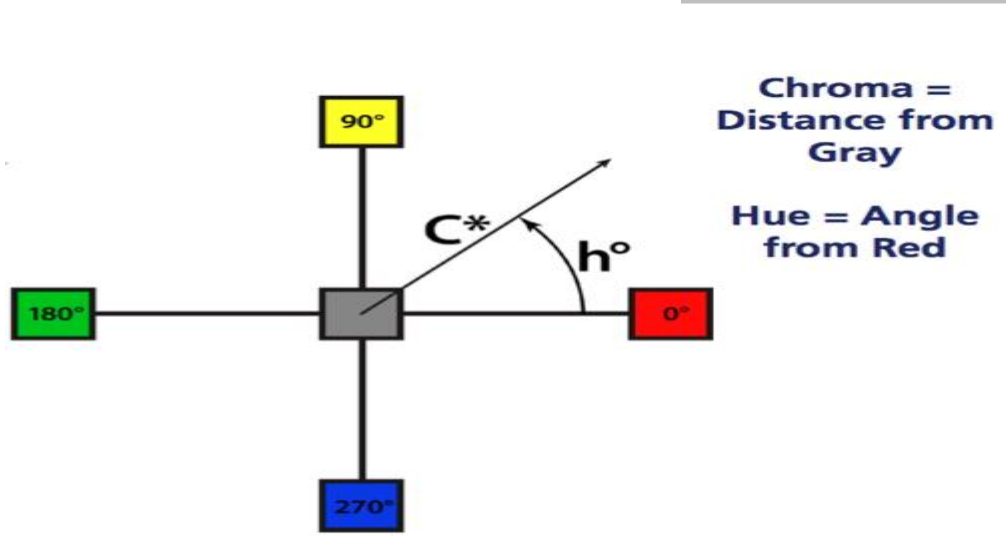
Example. Colorimetric properties of potato slices during microwave frying in sunflower oil are studied in terms of a CIE scale. As a standard, a $BaSO_4$ plate with *L*∗, *a*∗, and *b*∗ values of 96.9, 0.0, and 7.2, respectively was used. *L*∗, *a*∗, and *b*∗ values of potato slices are given in Table.

Determine *ΔE** values of the potato slices during frying and discuss the results.

Frying time (min)	*L**	*a**	*b**
2.0	69.63	0.567	39.20
2.5	67.47	2.467	45.10
3.0	63.67	3.033	46.00


Hue
Chroma
Value


Hue
Saturation
Value


90°
180°
0°
270°
C*
h°
Chroma =
Distance from
Gray
Hue = Angle
from Red