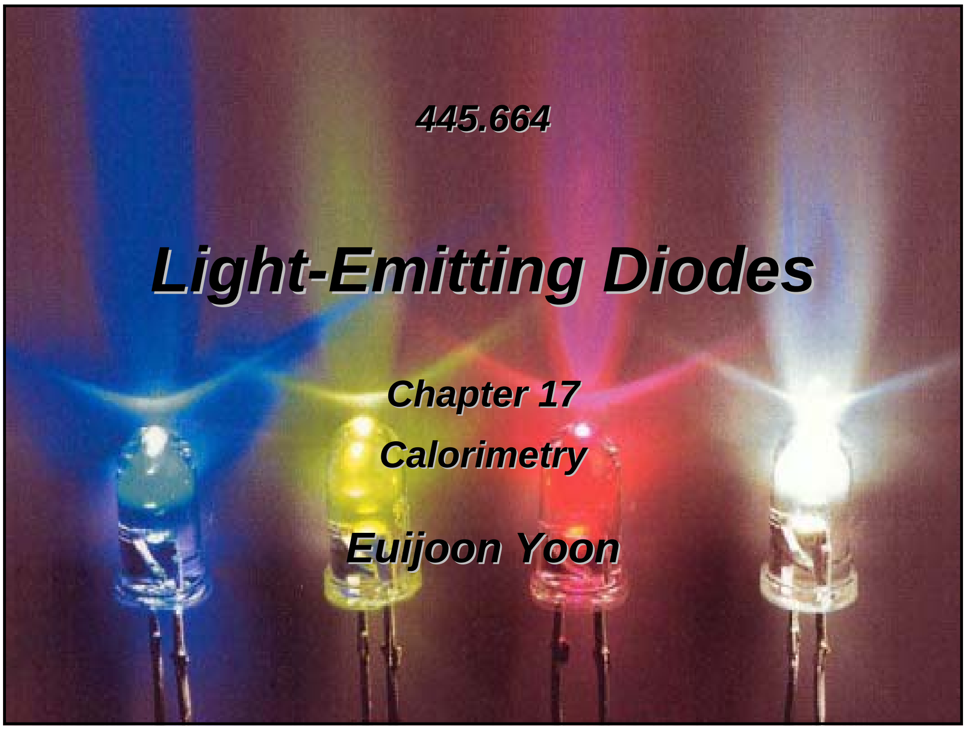


Colorimetry

- **The assessment and quantification of color**
- **Science of color**
- **The human sense of vision is different from the human sense of hearing**
  - Can distinguish two frequencies generated by a musical instrument
  - Mixing two monochromatic optical signals will appear to us as one color and we are unable to recognize the original dichromatic composition of that color.

Color matching functions

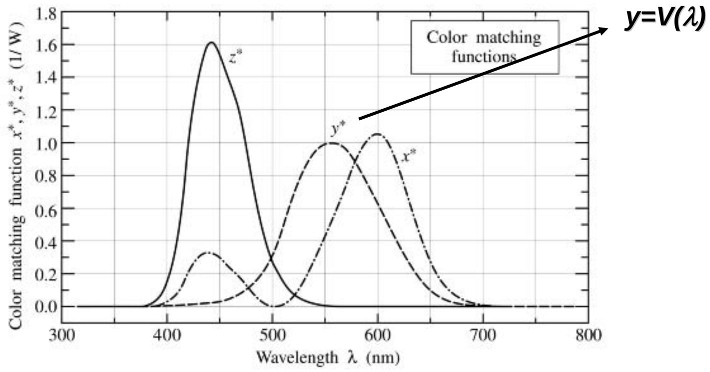


Fig. 10.2. Color matching functions. The numerical values of the y^* color matching function are identical to the eye sensitivity function $V(\lambda)$.

- ***The three color matching functions approximately correspond to the eye sensitivity of the red, green, and blue cones, respectively.***
- ***There are different standards for the color matching functions.***

Color matching functions

- ***The degree of stimulation of the three types of cones***

$$X = \int_\lambda \bar{x}(\lambda)P(\lambda)d\lambda$$

$$Y = \int_\lambda \bar{y}(\lambda)P(\lambda)d\lambda$$

$$Z = \int_\lambda \bar{z}(\lambda)P(\lambda)d\lambda$$

X,Y, and Z are tristimulus values.

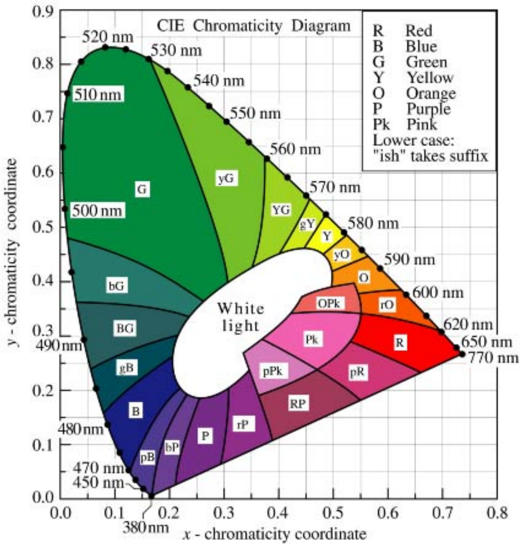
- ***chromaticity coordinates x, y***

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

z chromaticity coordinate not needed, since x + y + z = 1

- The value of a chromaticity coordinate is the stimulation of one particular cone normalized to the entire stimulation (X+Y+Z).

Chromaticity diagram



- ***Monochromatic or pure colors are found on the perimeter of the chromaticity diagram.***

Fig. 10.3. CIE chromaticity diagram. Monochromatic colors are located on the perimeter and white light is located in the center of the diagram (adopted from Gage *et al.*, 1977).

- ***White light is found in the center of the chromaticity diagram. (1/3,1/3,1/3)***

Equal-energy point

MacAdam ellipses

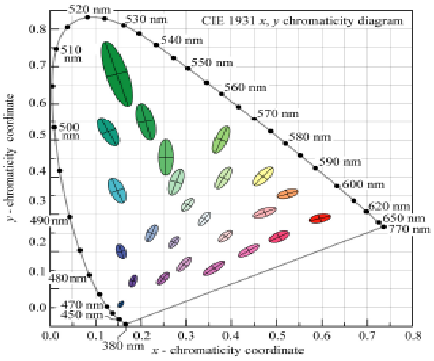


Fig. 17.5. MacAdam ellipses plotted in the CIE 1931 (x, y) chromaticity diagram. The axes of the ellipses are ten times their actual lengths (after MacAdam, 1943; Wright, 1943; MacAdam, 1993).

- **Two chromaticity points must have a minimum geometrical distance to yield a perceptible difference in color.**
- **Colors within a certain small region in the chromaticity diagram appear identical to human vision.**
- **Blue and green regions are very different in size.**
- **Humans can discern ~50,000 distinct chromaticities. Considering possible variation in luminance (brightness): number of differential colors ~10^6**

Uniform chromaticity diagram

- **It is very desirable for the color difference to be proportional to the geometric difference.**
- **Uniform chromaticity diagram**

$$u = \frac{4X}{X + 15Y + 3Z} \qquad v = \frac{6Y}{X + 15Y + 3Z} \qquad (CIE, 1960)$$

$$u' = \frac{4X}{X + 15Y + 3Z} \qquad v = \frac{9Y}{X + 15Y + 3Z} \qquad (CIE, 1976)$$

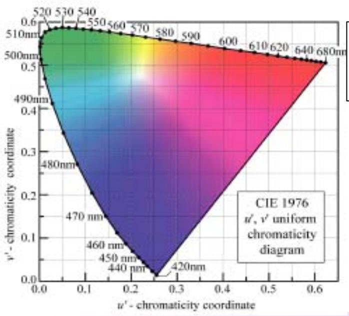
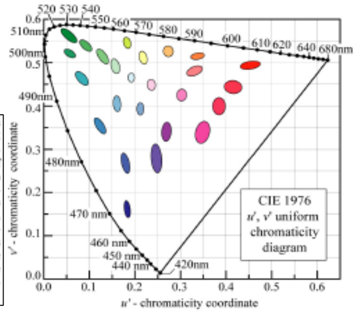
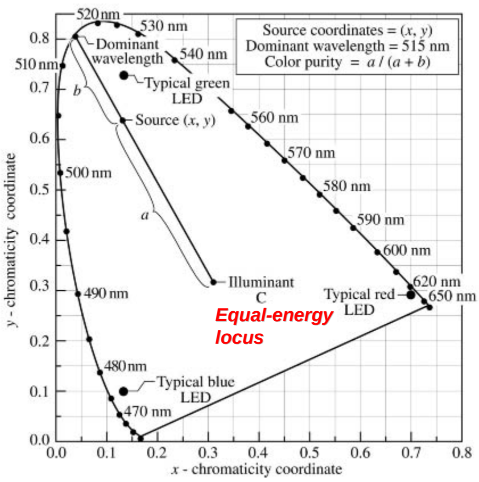


Fig. 17.6. CIE 1976 (u', v') uniform chromaticity diagram calculated using the CIE 1931 2° standard observer.

Fig. 17.7. MacAdam ellipses transformed to uniform CIE 1976 (u', v') chromaticity coordinates. For clarity, the axes of the transformed ellipses are ten times their actual lengths. Transformed ellipses are not ellipses in a strict mathematical sense, but their shapes closely resemble those of ellipses. The areas of the transformed ellipses in the (u', v') diagram are much more similar than the MacAdam ellipses in the (x, y) diagram.



Color purity and dominant wavelength



- ***Peak wavelength is a quantity used in physics and optics.***

Fig. 10.4. Chromaticity diagram showing the determination of the dominant color and color purity of a light source with chromaticity coordinates (x, y) using the *Illuminant C* as the white-light reference. Also shown are typical locations of blue, green, and red LEDs.

Color purity = a / (a+b)

- ***Dominant wavelength is used by human vision.***

- ***As the spectral linewidth of a light source gets broader, the color location moves towards the center of the chromaticity diagram.***

LEDs in chromaticity diagram

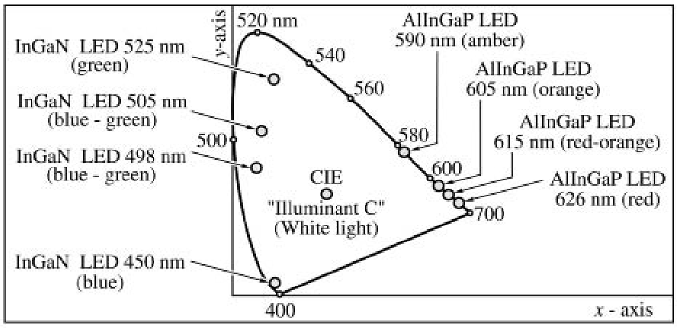


Fig. 10.5. Location of LED light emission on the chromaticity diagram (adopted from Schubert and Miller, 1999).

- ***Red and blue LEDs are near perimeter.***
- ***Green LEDs are not at perimeter but are shifted towards center.***
- ***Color purity or color saturation***