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Light-Emitting Diodes

Chapter 19.
Color mixing and color rendering

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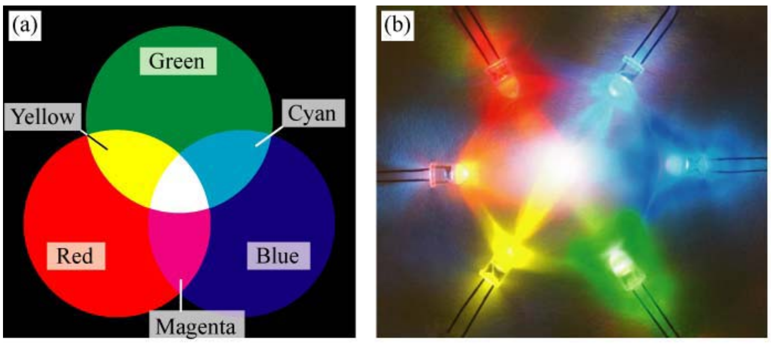
Color mixing - examples



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- **RGB color mixing**
- **Color gamut**
- **Gamut size increases with the number of light source.**

Additive color mixing

- **In LED displays, three different types of LEDs, usually emitting in the red, green, and blue, are used. The three colors are mixed so that the observer sees a mixture of the three colors.**

- **If the spectral linewidth of the three sources is much narrower than the color matching functions, then**

$$X = \bar{x}(\lambda_1)P_1 + \bar{x}(\lambda_2)P_2 + \bar{x}(\lambda_3)P_3 \qquad L_1 = \bar{x}(\lambda_1)P_1 + \bar{y}(\lambda_1)P_1 + \bar{z}(\lambda_1)P_1$$

$$Y = \bar{y}(\lambda_1)P_1 + \bar{y}(\lambda_2)P_2 + \bar{y}(\lambda_3)P_3 \qquad L_2 = \bar{x}(\lambda_2)P_2 + \bar{y}(\lambda_2)P_2 + \bar{z}(\lambda_2)P_2$$

$$Z = \bar{z}(\lambda_1)P_1 + \bar{z}(\lambda_2)P_2 + \bar{z}(\lambda_3)P_3 \qquad L_3 = \bar{x}(\lambda_3)P_3 + \bar{y}(\lambda_3)P_3 + \bar{z}(\lambda_3)P_3$$

(P_1, P_2, and P_3 are the optical powers emitted by the three sources.)

- **The chromaticity coordinates of the combined light is given by**

$$x = \frac{x_1L_1 + x_2L_2 + x_3L_3}{L_1 + L_2 + L_3}, \quad y = \frac{y_1L_1 + y_2L_2 + y_3L_3}{L_1 + L_2 + L_3}$$

- The chromaticity coordinate of the multi-component light is a linear combination of the individual chromaticity coordinates weighted by the L_i factors.

Color mixing and color rendition

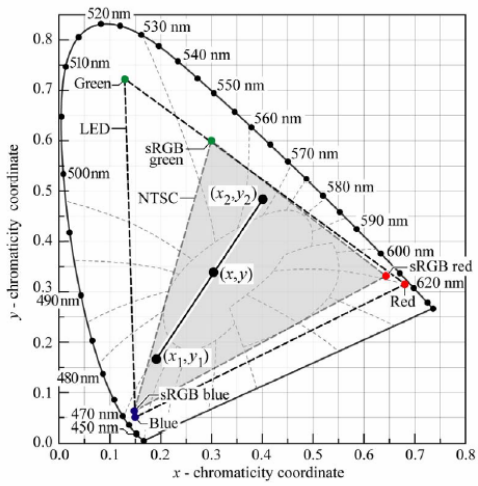

Fig. 11C.1. Principle of color mixing illustrated with two light sources with chromaticity coordinates (x_1, y_1) and (x_2, y_2). The resulting color has the coordinates (x, y). Also shown is the triangular area of the chromaticity diagram (color gamut) accessible by additive mixing of a red, green, and blue LED. The locations of the red, green, and blue phosphors of the sRGB display standard ($x_r = 0.64$, $y_r = 0.33$, $x_g = 0.30$, $y_g = 0.60$, $x_b = 0.15$, $y_b = 0.06$) are also shown. The sRGB standard is similar to the NTSC standard.

- **Color gamut; represents all colors that can be created by mixing primary colors, e.g. red, green, and blue. Webster: n. the entire scale or range**
- **Gamut of Red-Green-Blue light source has triangular shape.**
- **Area of gamut matters for displays, color printers, etc.**

Color rendition

- A light source has color rendition capability

  : Capability to render the true colors of an object

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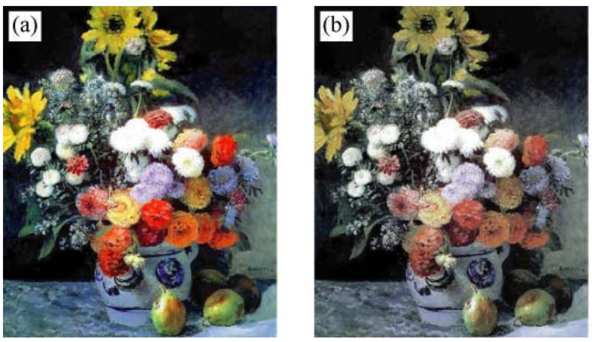
Color rendering index

- Color rendering index (CRI)
  - A measure of the ability of the illuminant to faithfully render the colors of physical objects illuminated by source



High CRI   Low CRI

Calculation of the CRI

- For the calculation of the CRI, the reference source is chosen as follows,
  - If the chromaticity point of the test source is located *on* the planckian locus, the reference source is a planckian black-body radiator with the same CT as the test source
  - One of the standardized CIE illuminants can be used as a reference source (CIE, 1995).
  - Planckian black-body reference source is assumed to have perfect color rendering properties. CRI=100
  - The selection of the reference source
    - Critical importance when calculating the CRI of the test sources.

Test-color samples

- CIE general CRI

$$CRI_{general} = \frac{1}{8}\sum_{i=1}^{8} CRI_i \qquad CRI_i = 100 - 4.6\Delta E_i^*$$

- ***ΔE_i^* : The quantitative color change that occurs when a test-color sample is illuminated with, first, the reference illumination source ("reference source"), and subsequently with the test illumination source ("test source").***
- **ΔE_i^* plays key role in the calculation of the CRI.**

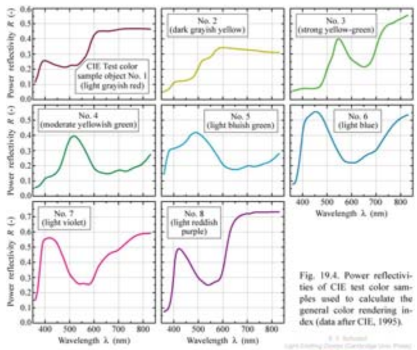


Fig. 19.4. Power reflectivities of CIE test color samples used to calculate the general color rendering index (data after CIE, 1995).

- The test-color samples are defined in terms of their spectral reflectivity.
- The general color-rendering index is calculated from these eight test-color samples.

Special color-rendering indices

- In addition to the test-color samples (number 1-8) used to calculate the general color rendering index,
  - six supplemental test-color samples (number 9-14) are used.
- Further assess the color rendering capabilities of test sources.
- CRI_9 to CRI_{14}
  : Special color-rendering indices 9-14

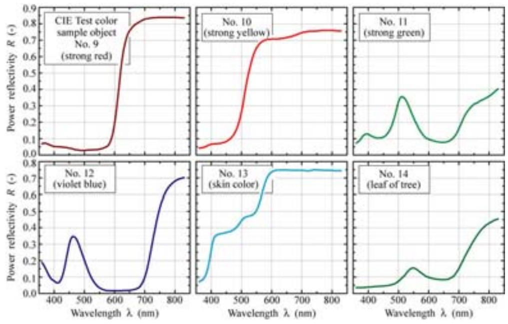
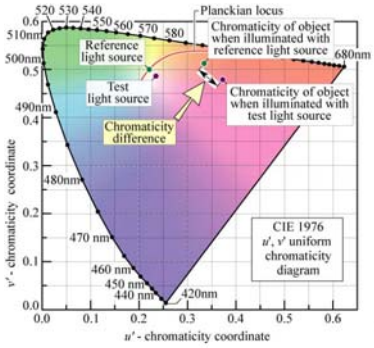


Fig. 19.5. Power reflectivities of CIE test color samples used to calculate the special color rendering indices $CRI_9 - CRI_{14}$ (data after CIE, 1995).

- The reflectivity spectra and the numerical values of the reflectivity of the supplemental test-color samples.

Chromaticity difference



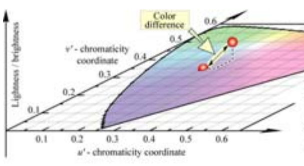


Fig. 19.7. Illustration of color difference in a three-dimensional color space consisting of the horizontal chromaticity plane and the vertical brightness / lightness axis.

- Test source is located slightly off the planckian locus.
- Reference source is a planckian source with the least possible distance from the test-source chromaticity point.
- 3rd axis could be added to the chromaticity diagram for a graphical representation of object lightness.

Color rendering indices example

Light source	*Color rendering index*
Sunlight	100
Quartz halogen W filament light	100
W filament incandescent light	100
Fluorescent light	60 – 85
Phosphor-based white LEDs	60 – 90
Trichromatic white light LEDs	60 – 90
Hg vapor light coated with phosphor	50
Na vapor light	40
Hg vapor light	20
Dichromatic white light LEDs	10 – 60
Green monochromatic light	– 50

Table: Color rendering indices (CRI) of different light sources.