Lighting: Color

Academic Resource Center

26-Feb-2009
Objectives

- Understand Basics of Color
  - Additive (sources) vs Subtractive (reflective) Color
  - Chromacity Diagram
  - Black Body Radiative
Time

- Tasks take more time when visibility is reduced by low light levels or low contrast.
- If tasks must be completed quickly, light levels must be adequately high.
At age 50, human beings – on average – received half the light on the retina that they did at age 20.
A Few More Issues

- Luminance Ratios
- Veiling Reflections
- Glare
  - Direct Glare
  - Reflected Glare
The Prism and Color

- Newton showed that a prism could be used to separate daylight into individual components through refraction.
- Short wavelengths (blue) refract more than long wavelengths (red).
Spectral Color

- Light of a single particular wavelength is called a pure spectral color.
  - Lasers emit pure spectral colors
  - Chemical processes can give rise to several spectral lines
  - Prisms refract light so the light in any particular direction is a pure spectral color
    - One type of optical filter utilizes a prism and a moveable slit

To the right is the Balmer Series of spectral lines for H, Hg, and Ne.
## Spectral Color to Wavelength Mapping

<table>
<thead>
<tr>
<th>COLOR</th>
<th>WAVELENGTH</th>
<th>ENERGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>700 nm</td>
<td>1.771 eV</td>
</tr>
<tr>
<td>Orange</td>
<td>600 nm</td>
<td>2.067 eV</td>
</tr>
<tr>
<td>Yellow</td>
<td>580 nm</td>
<td>2.138 eV</td>
</tr>
<tr>
<td>Green</td>
<td>500 nm</td>
<td>2.480 eV</td>
</tr>
<tr>
<td>Blue</td>
<td>450 nm</td>
<td>2.765 eV</td>
</tr>
<tr>
<td>Violet</td>
<td>400 nm</td>
<td>3.100 eV</td>
</tr>
</tbody>
</table>

R. O. Y. G. B. V. – the colors of the rainbow
Color is Perception not Spectrum

- While we do perceive different wavelengths of light as different colors, do not make the mistake that wavelength = color.
- While different wavelengths of monochromatic light will have different colors, different combinations of wavelengths can have the same color
  - Two samples of light with distinctly different spectra might be perceived as the same color
Perception of Monochromatic Light

- Light as a part of the electromagnetic spectrum
  - Shorter wavelengths near the 400nm range of the spectrum produce a “blue” visual sensation
  - Medium wavelengths in the 500-600nm range produce a “yellow to green” sensation
  - Longer wavelengths produce a “reddish” sensation
Spectral Power Distribution

Illumination engineers call the spectrum of light the Spectral Power Distribution (SPD)

Noontime Sunlight

Fluorescent Lamp

Cool White 4200K
Color Needs Light
Perception of Object Color

Object color perception is the result of the light source interacting with the object.
In order to perceive the color of an object, that color must be present in the light source.
Sources: Additive Color Mixing
Subtractive Color Mixing

Mixtures of Pigments
Subtractive Mix
Chromacity

One way of quantifying color is by chromacity which is independent of luminance. It comes from trying to encode color as a combination of three functions which approximate the response of our cones to light.
Black Body Color Temperature

- If we heat up a blackbody it will glow. The color is related to temperature. Thus can use a black body radiator as a color reference.
Correlated Color Temp (CCT)

Correlated Color Temperature (CCT) is a measure of “warmth” or “coolness” of a light source’s appearance. It is measured in degrees kelvin, expressed in kelvin (K) and is the closest possible match to Color Temperature

Note:
Sources with a bluer spectrum have a higher CCT but are called “colder” since they look more like ice.
Sources with a redder spectrum have a lower CCT and are called spectrum “warmer” since they look more like fire.
Effect of CCT

Lamps of different CCT renders objects differently
Effects of CCT on Color Rendering

\[ \text{CCT} = 2500\text{K} \]

\[ \text{CCT} = 3500\text{K} \]

\[ \text{CCT} = 5000\text{K} \]
Color Rendering Index (CRI) is a unit of measure that defines how well colors are rendered by different illumination conditions in comparison to a standard.

The higher the number, the more likely the light source will render objects “naturally.”

<table>
<thead>
<tr>
<th>Color Rendering Index (CRI)</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>Poor</td>
<td>Fair</td>
<td>Good</td>
<td>Excellent</td>
<td></td>
</tr>
</tbody>
</table>

- Poor
- Fair
- Good
- Excellent
Measuring CRI

- CRI is computed by comparing the colors of 8 samples (see below) with a given lamp to the colors rendered by a black body radiator of the same temperature.
Effects of CRI

Color Rendering

Cool White  Designer 841
## Effects of CRI

<table>
<thead>
<tr>
<th>CRI Range</th>
<th>Light Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fair 50–60 CRI</td>
<td>Standard Warm White Fluorescent, Standard Cool White Fluorescent</td>
</tr>
<tr>
<td>Better 70–80 CRI</td>
<td>Thin Coat Tri-Phosphor Fluorescent</td>
</tr>
<tr>
<td>Best 80–90 CRI</td>
<td>White High Pressure Sodium, Warm Metal Halide, Thick Coat Tri-Phosphor Fluorescent</td>
</tr>
<tr>
<td></td>
<td>90–100 High CRI Fluorescents, Incandescent and Tungsten-Halogen</td>
</tr>
</tbody>
</table>

**ARC.**
Introduction

- The lamp is the source of artificial lighting systems
  - Converts electricity to light through a variety of mechanisms

- Lamp is combined with a fixture (reflectors) to create a luminaire
  - Fixtures are designed to work with certain lamps
    - Lamps vary in their output directionality and their heat generation characteristics
Lamp Families

- **Incandescent (Regular, Halogen)**
  - Heated filament produces radiation

- **Cold Cathode (Neon, Argon)**
  - Visible arc in a tube

- **Fluorescent**
  - Arc in a tube generates UV which excites phosphors which emit visible light

- **High Intensity Discharge (HID)**
  - Visible arc through a very high pressure vapor
    - Mercury Vapor, Sodium Vapor, Metal Halide

- **Light Emitting Diodes (LED)**
  - LED are semiconductors and light is emitted from electron when it combines with a hole
Important Lamp Quantities

- **Efficacy**
  - Lamp efficiency – ratio of lumens out to electrical power in [lumens/watt or LPW]

- **Lamp Life (mortality)**
  - The life of a lamp is defined as the time when 50% of an initial population of lamps have burnt out.
    - There is usually huge statistical spread

- **Lamp Lumen Depreciation**
  - Lumens output compared to initial lamp as a function of time. LLD is the fraction left at 40% of lifetime of the lamp (some manufacturers use 60% or 70%)
Lamp Efficacy

- Efficacy of common lamps

- **Incandescent/Halogen**: 10 - 30 LPW
- **Fluorescent**: 60 - 109 LPW
- **Mercury**: 40 - 58 LPW
- **Metal Halide**: 67 - 115 LPW
- **High Pressure Sodium**: 71 - 145 LPW
- **Low Pressure Sodium**: 100 - 180 LPW

*Lumens Per Watt - Including Ballast*
Lamp manufacturers test thousands of lamps and develop lamp mortality curves. The lamp life is the 50% mark.
Lamp Lumen Depreciation (LLD)

- LLD is the fraction of initial lumen output at 40% of lifetime
  - Some lamp output decreases more quickly

- Incandescent: LLD > 90%
- Fluorescent: 60%<LLD<90%
- Halide: 60% < LLD < 80%
- Sodium: 80% < LLD < 90%
- LED: LLD – not really known