

**Benjamin Moore®**

# The Science of Color and Light

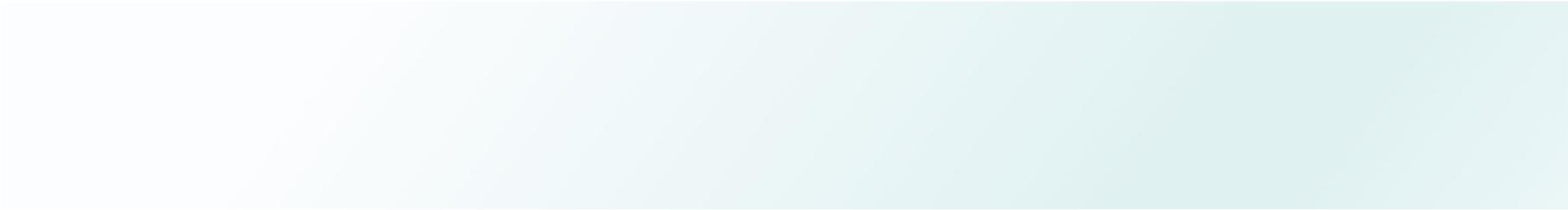
[www.benjaminmoore.com](http://www.benjaminmoore.com)



Course Number EL206

Friday, June 22, 2018

Learning Units 1.0 LU, HSW, GBCI, RIBA



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Questions related to specific products and services may be addressed at the conclusion of this presentation.

## Speaker List

Toni Germie

Architectural & Design Rep

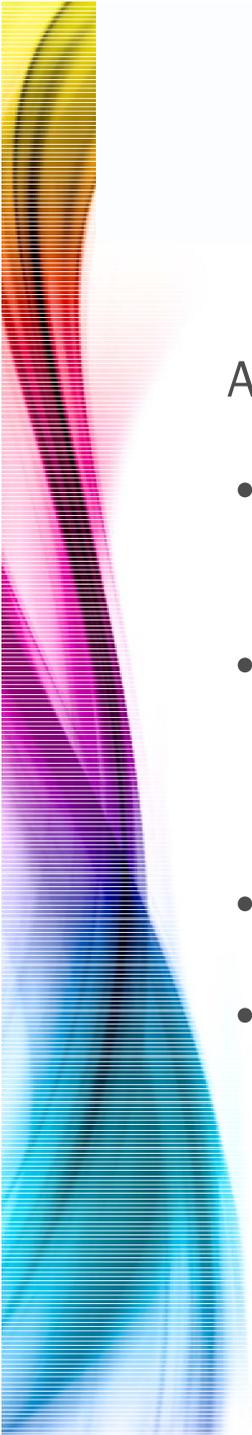
Benjamin Moore & Co.



## Course Description

This course will:

Investigate the interplay of color and light: this in depth course explores the design impact of lighting, Color Temperature, Color Rendering Index (CRI), and Light Reflectance Value (LRV). Additionally, we'll identify problems that occur as a result of product substitution and color matching.



# Learning Objectives

At the end of this program, participants will be able to:

- Understand the role of light and the process that occurs between the brain and the eye for humans to see and perceive color.
- Compare the characteristics of different light sources, specifically color temperature, and color rendering index and their impact on color.
- Gain a deeper understanding of LRV.
- Identify problems that occur due to product substitution and color matching.

# Color and Light



- Color is determined by light
- Enlightenment period - color treated as a science
- Lighting designer: light intensity and color temperature
- Scientist: physics and properties of light at different wavelengths
- Design Professional: color as scientific and decorative

# Evolution of Light



**13.7 Billion  
years ago  
“The Big Bang”**

**4 Billion BC  
“The Sun”**

**400,000 BC  
“Fire”**

**5,000 BC  
“Oil Lamps”**

**3,000 BC  
“Candles”**

*Primary source of  
light in the  
17<sup>th</sup> Century*

# Evolution of Light



**1809**  
Humphrey Davy Invented  
“Incandescent Filament”

**1814**  
“Gas Lamps”

*US and Europe  
Street Lamps  
power by gas*

**1853**  
“Kerosene  
Lamps”

*Hundreds of people  
flocked on New Years  
Eve to see Edison’s  
invention in his Menlo  
Park laboratory*

**1879**  
“Edison Inc.  
Lamps”

# Evolution of Light



**1936**  
“Fluorescent  
Lamps”

**1955**  
“Fiber Optics”

**1959**  
“Halogen Lighting”

**1960**  
“Lasers”

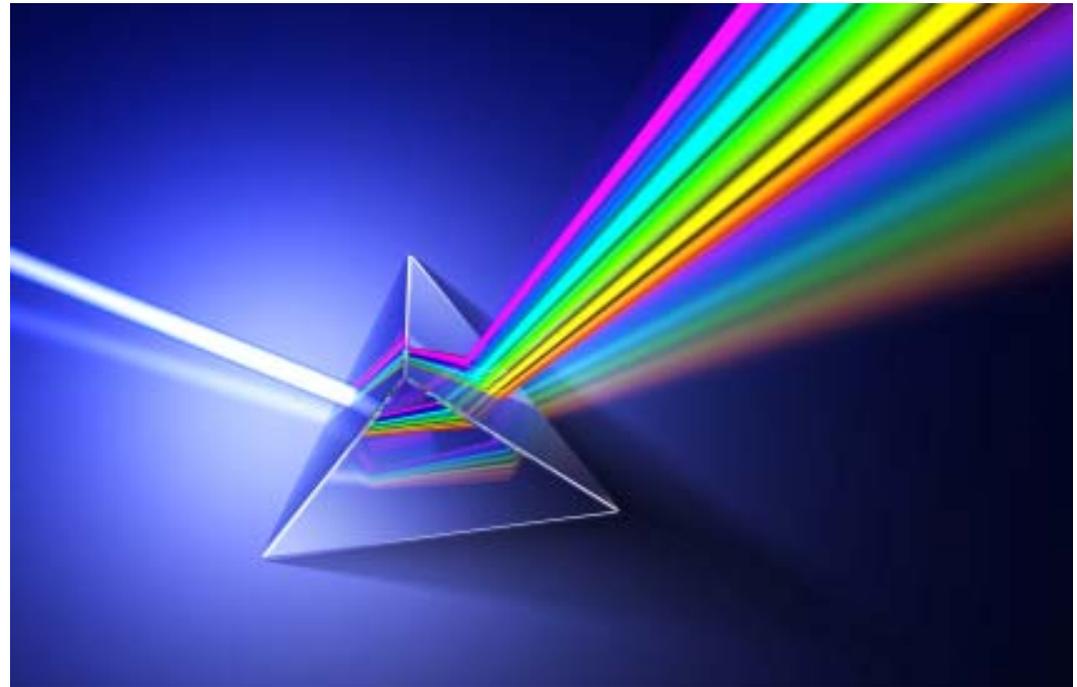
**1962**  
Nick Holonyak Jr.  
LED-Red  
“Father of LED”

*Introduced to  
the public at  
the New York  
Worlds Fair in  
1939*

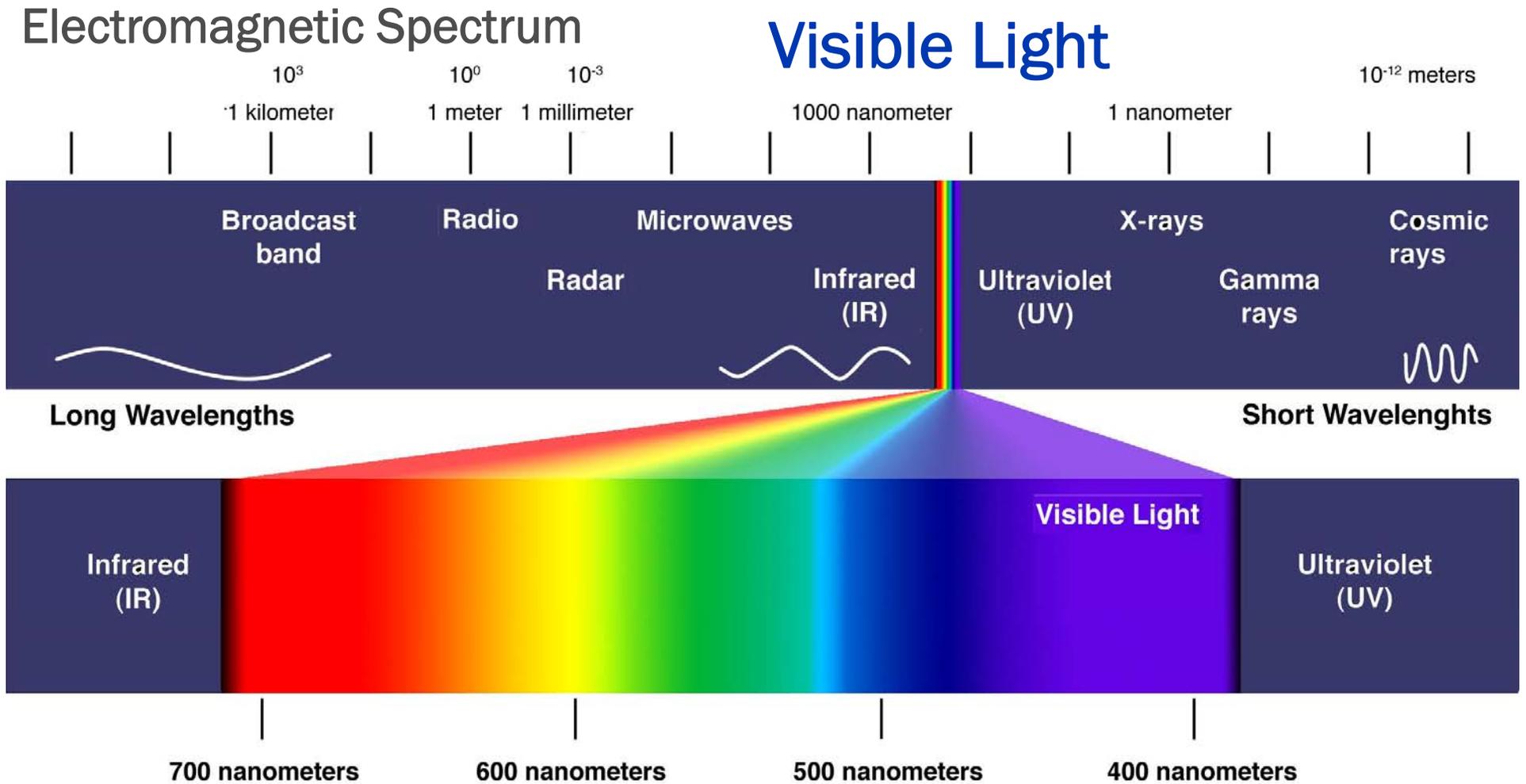


# Color and the Impact of Light

- 1666 – Sir Isaac Newton discovered light is composed of a spectrum of colors
- Red, orange, yellow, green, blue, indigo, and violet  
*(the colors of the rainbow)*

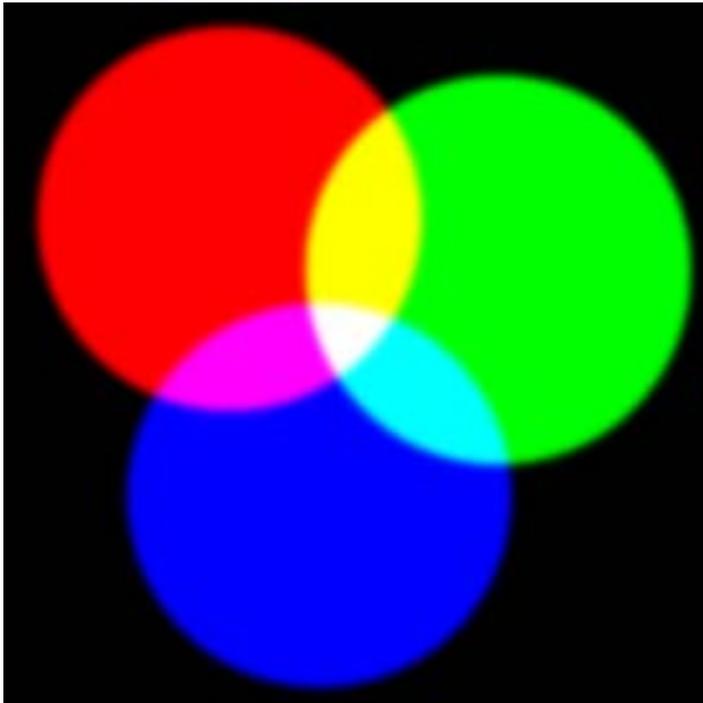


# Electromagnetic Spectrum



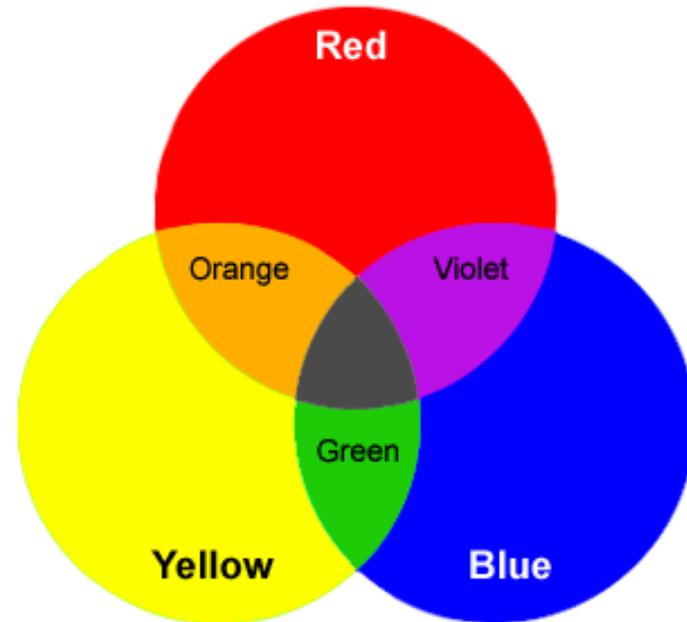
# Additive / Subtractive Color

## Additive Color



Three primary colors of light added together in equal amounts = white light

## Subtractive Color



Three primary pigment colors (substances) combined = black

# Subtractive Color and the Color Wheel

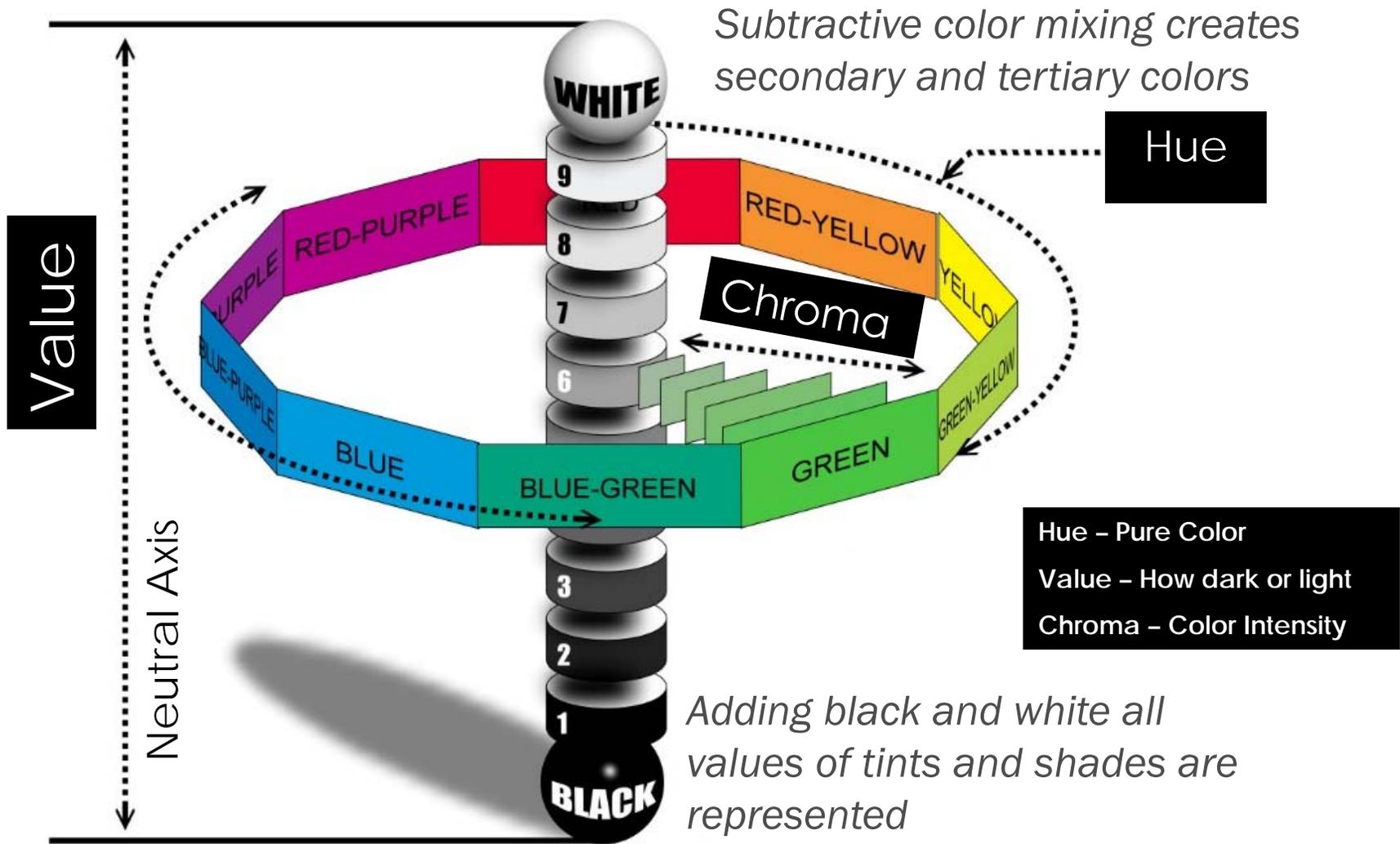
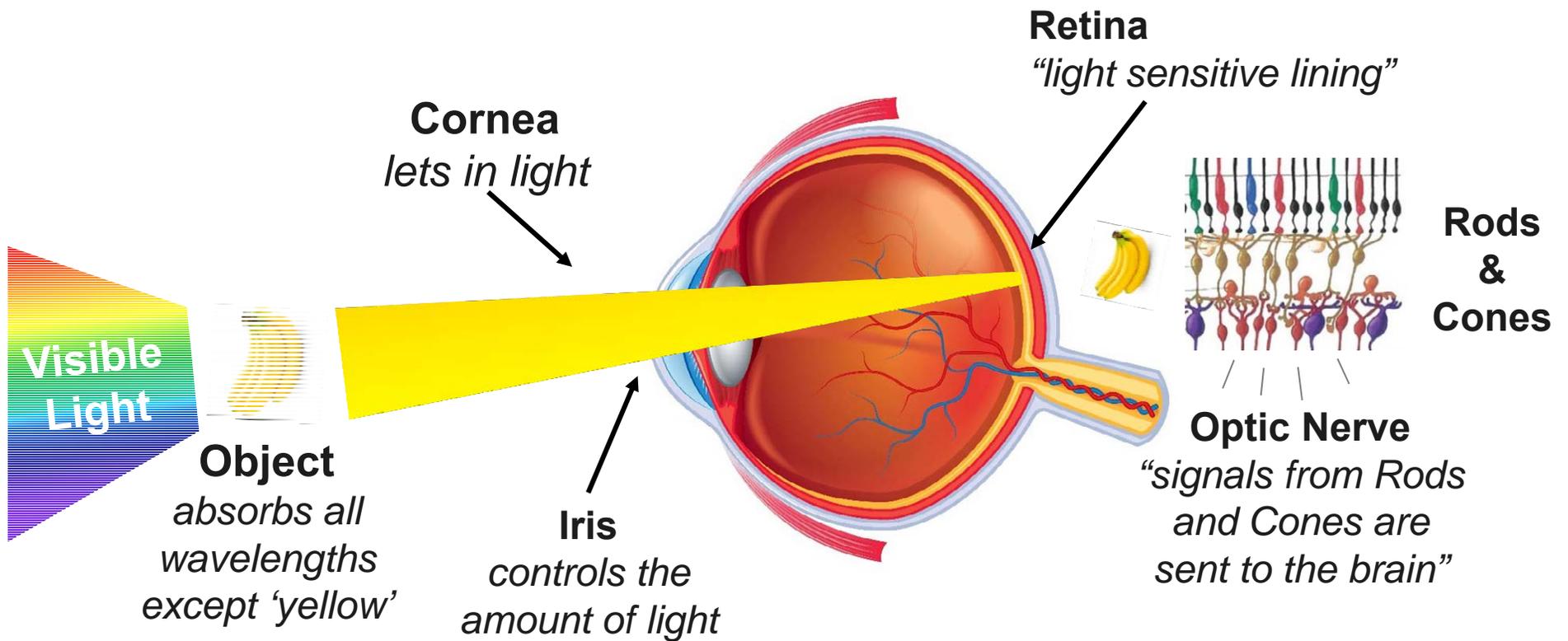
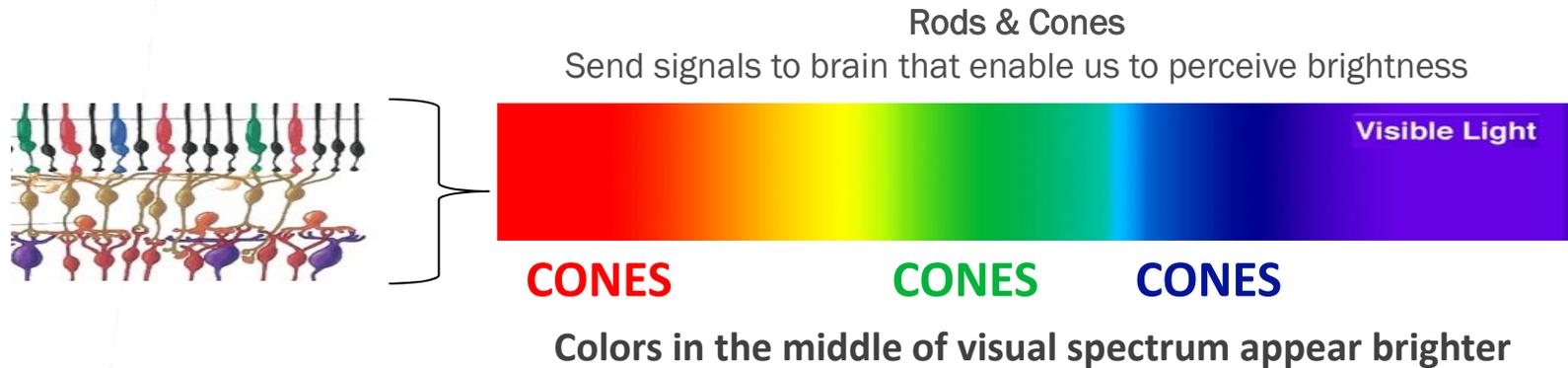


Image : Munsell Color Space

# The Human Eye



# Rods and Cones



- **Rods** perceive light and dark (no color) and are used primarily at night (which is why you don't see colors at night)
- **Cones** sense colored light – sensitive to red, green, and blue
- **Cone fatigue** happens when a specific wavelength, or color, of light, is emitted in high intensity; the relevant cones become fatigued and less sensitive to that wavelength.



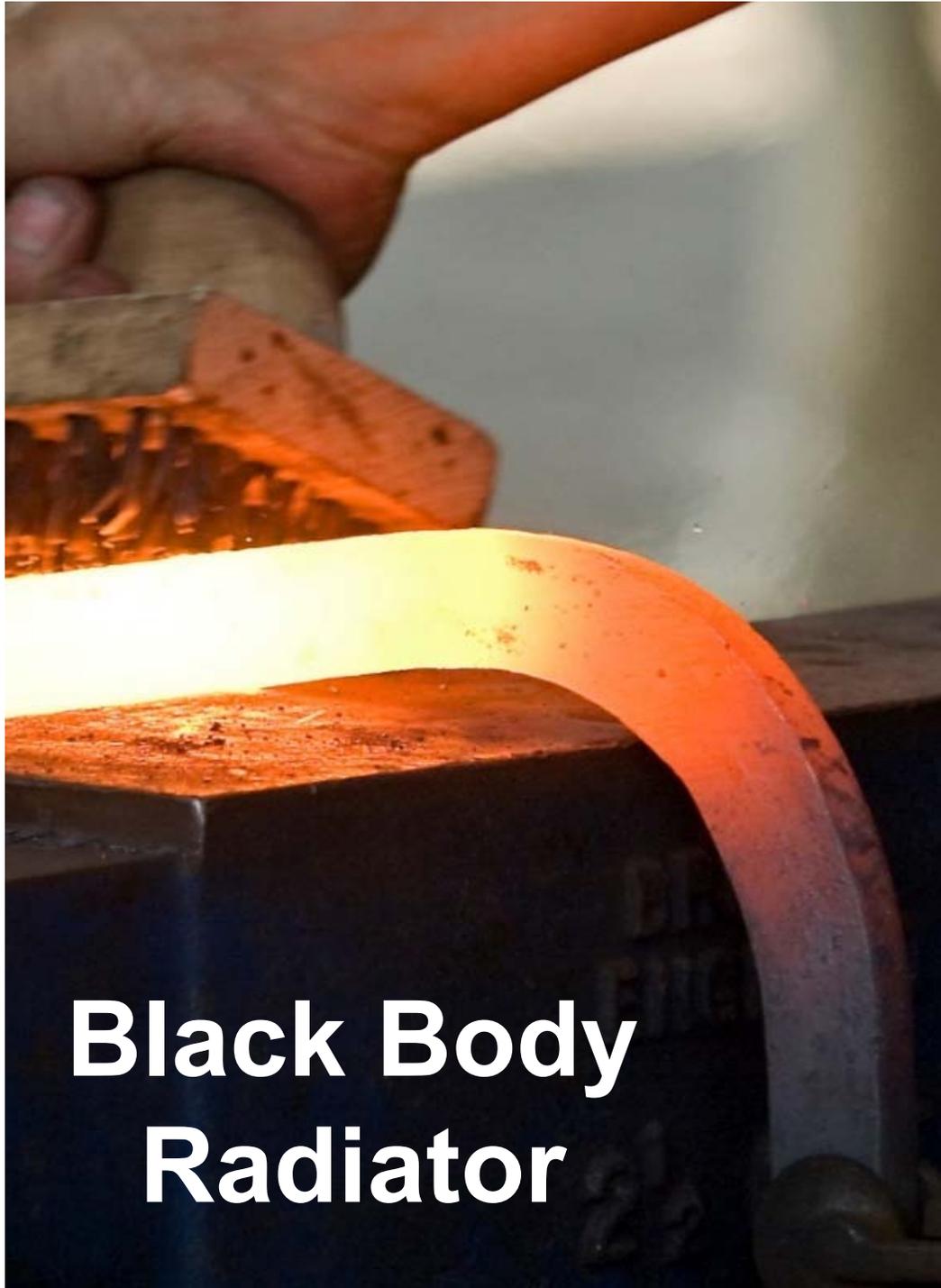


## Characteristics of Lighting

Correlated Color Temperature  
(CCT)

Color Rendering Index (CRI)

Spectral Power Distribution (SPD)



- An ideal radiator that absorbs light at all electromagnetic wavelengths
- When heated the light emitted changes colors
- Key to determining color temperature

# Correlated Color Temperature (CCT)

0 Kelvin  
-273 ° C

10000 Kelvin  
9,727 ° C

2000-3000K  
Morning Light at Sunrise  
3000-2000K  
Evening Light at Sunset

5500K - 9600K  
Afternoon or Daylight appears more blue  
(Varies dramatically at different times of day)

- 1850K Candle
- 2700K Incandescent
- 2700K CFL
- 3000K Halogen
- 2700-3200K LED Warm White

- 4000K Clear Metal Halide
- 4100K Cool Fluorescent
- 4000-4500K LED Natural White

- 5000-6000K LED Day White

- 7000-7500K LED Cool White

2000K 3200K

5000K 5500K

9500K

WARM

COOL

# Color Rendering Index (CRI)

- CRI is a standardized method of assessing the ability of a light source to render color accurately
- The higher the CRI the better the light is at rendering colors
- A CRI of  $>80$  is adequate for interior spaces

Fair  
50-70 CRI

Better  
70-80 CRI

Best  
80-100 CRI



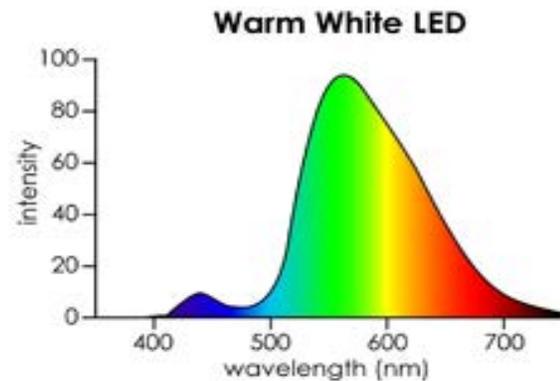
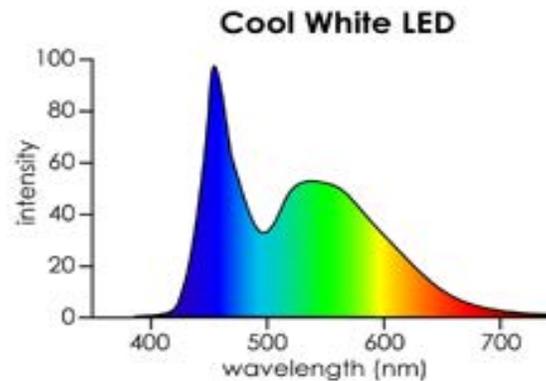
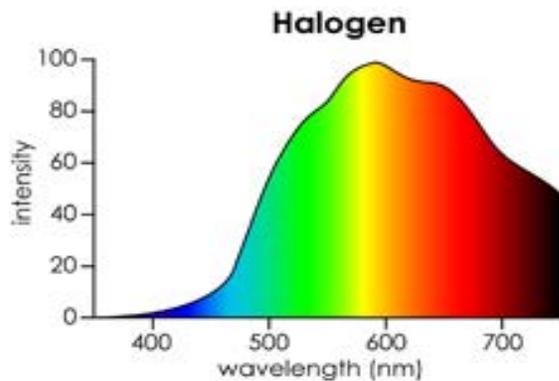
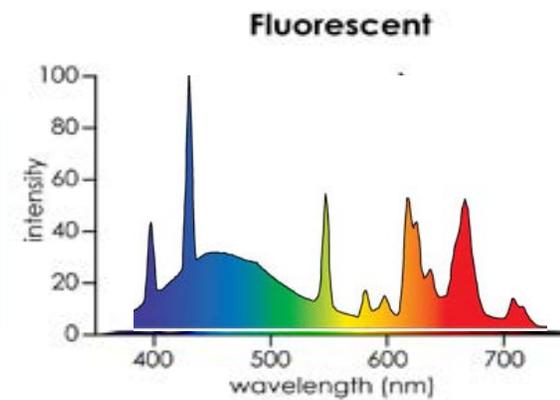
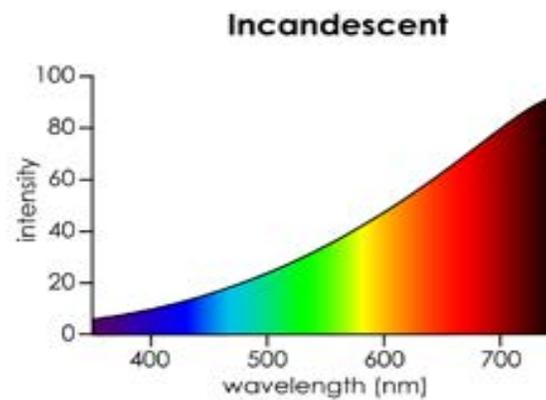
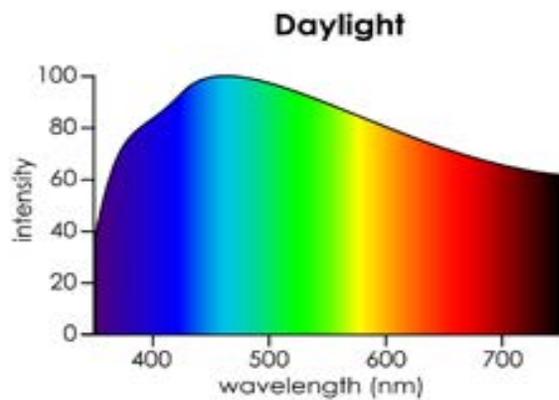
Source: [EnergyStar.Gov](http://EnergyStar.Gov)

# Spectral Power Distribution

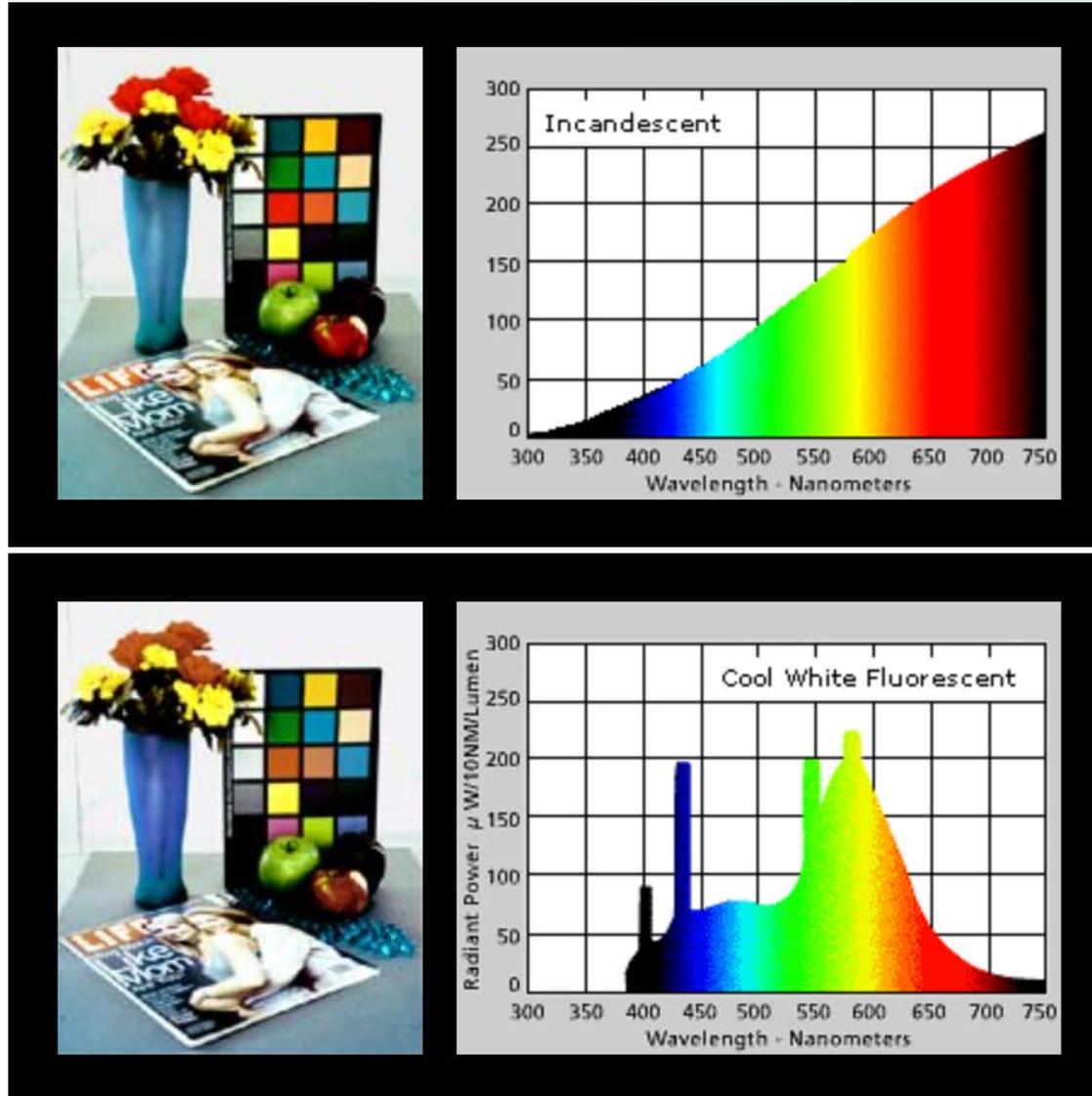
Visible Light



Source	CRI	CCT
LED	80	2700 K
Incandescent	100	2700 K



# Spectral Power Distribution of Light Source



# IES TM<sub>30-15</sub>

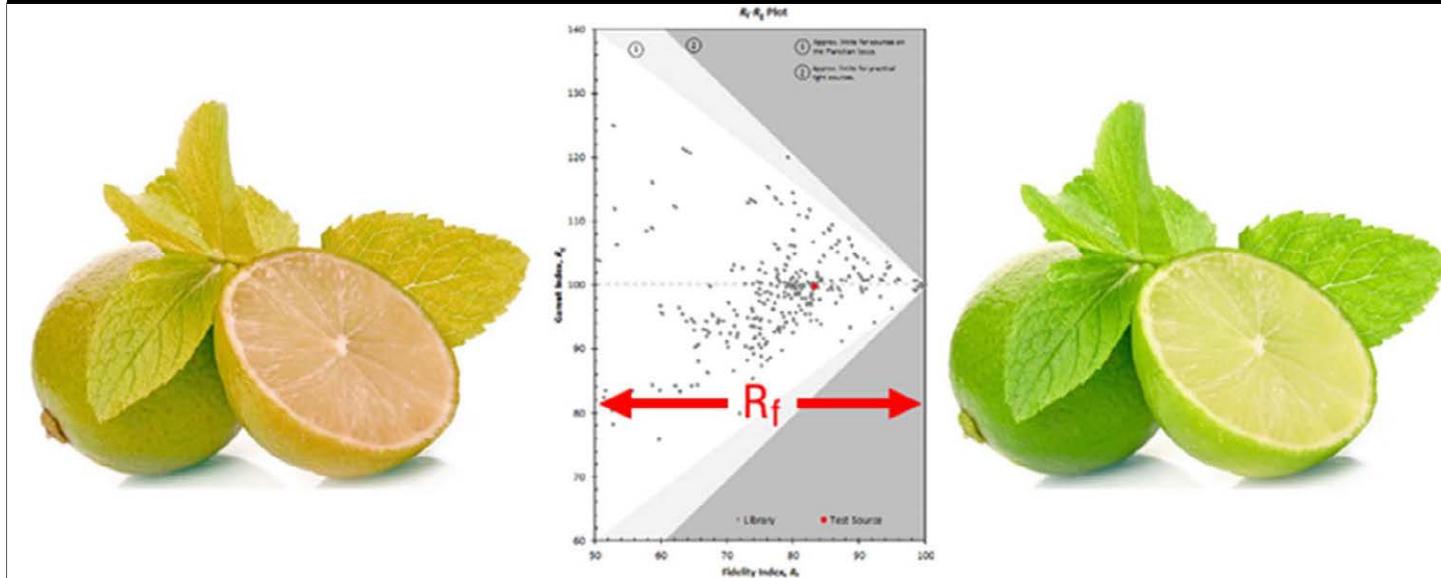
- A comprehensive system for calculating objective information
- Benefit specifiers, manufacturers, and researchers
- Informed decisions about light source spectrum
- Ability to evaluate tradeoffs between efficiency and color rendering
- Transitioning from CRI to IES TM30-15 will take time!

**Color Vector Graph (Interprets the average Hue / Chroma shifts)**



**For more information on TM30-15 [WWW.IES.ORG](http://WWW.IES.ORG)**

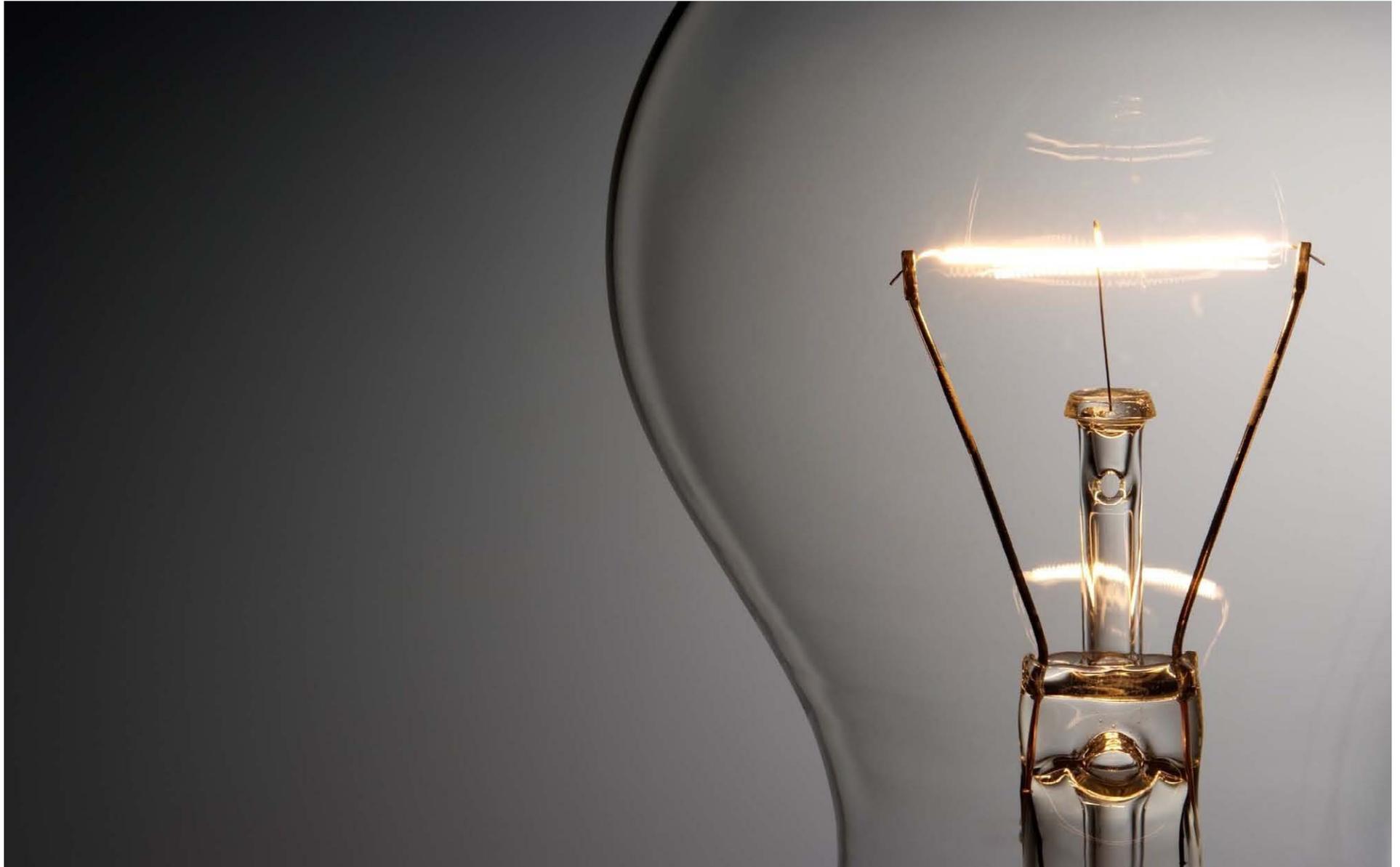
Fidelity Index =  $R_f$  Measures closeness to reference



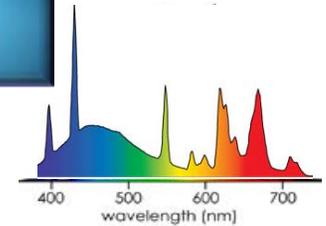
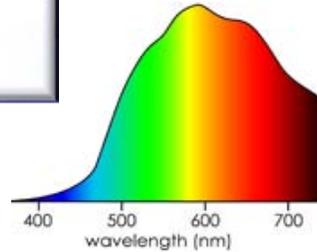
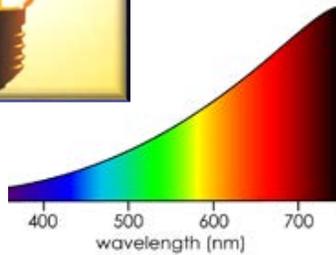
Gamut Index =  $R_g$  Measures Increase/Decrease in Chroma



# Artificial Lighting



# Incandescent / Halogen / Compact Fluorescent Lighting



## Incandescent

- More energy at red end of spectrum
- Warm light - Yellow cast
- Colors appear warm, with reds and yellows enhanced – blues and green dulls
- Average color temperature 2700K / CRI 100%
- 1,000 hours

## Halogen (A-Style)

- Closest to daylight
- Best light for color rendering
- Color Temperature 3000K / CRI 100%
- 2,000 – 3,000 hours
- Burns at continuous level of brightness
- When dimmed light turns more amber and orange

## Compact Fluorescent Light (CFL)

- Spike Blue, Green, Red
- Much bluer in tone
- Colors appear cool with blues and greens enhanced – reds and yellows muted
- Color temperatures range from 2700K – 6500K / CRI 80%+
- 8,000-10,000 hours

# Incandescent/Halogen/CFL Applications



# Linear Fluorescent (Tube) Lighting

T5 5/8" 3rd Generation 2000s



T8 1" 2<sup>nd</sup> Generation 1980s

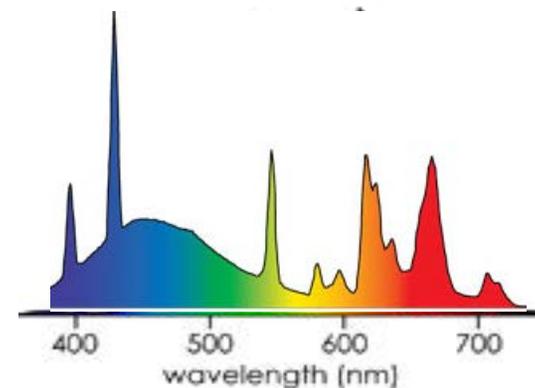


T12 1.5" 1<sup>st</sup> Generation 1930s  
Phased out in 2012

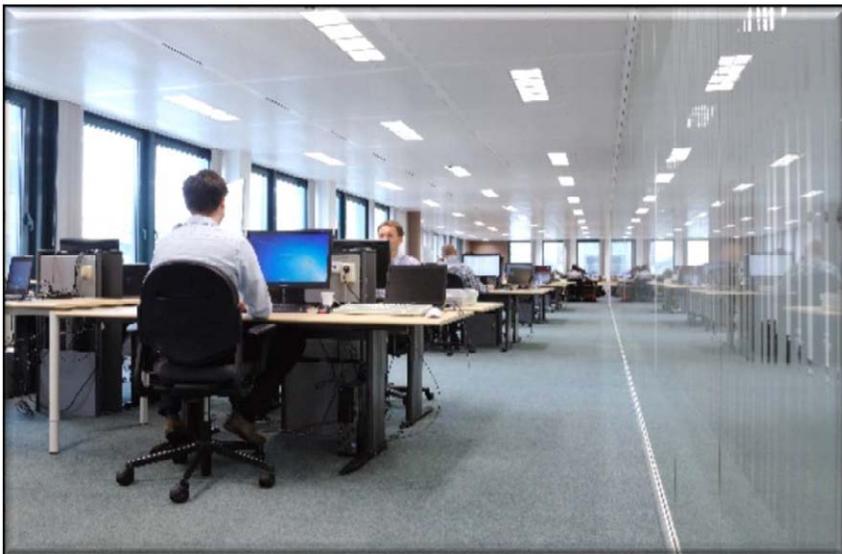


## Linear Fluorescent Light

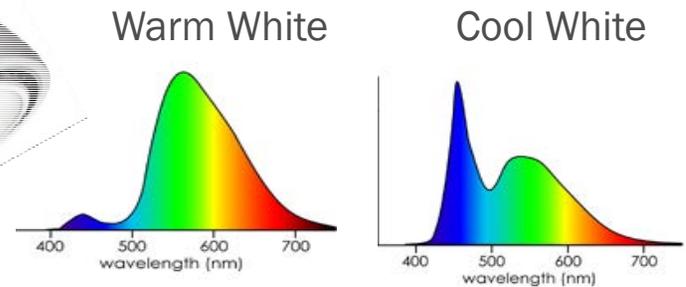
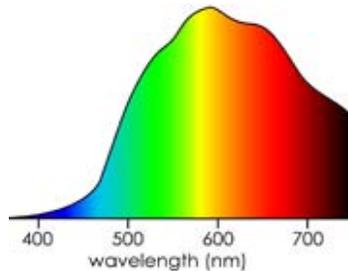
- Spikes at blue end of spectrum – enhances cooler colors
- Much bluer in tone
- Colors appear cool with blues and greens enhanced – reds and yellows muted
- Color Temperatures range from Warm 2700K to Cool 6500K / CRI 80+
- 8,000 – 10,000 hours
- Diffused Light – Evenly distributed, reduces harsh shadows



# Fluorescent Applications



# Recessed Lighting



## Halogen MR & PAR

- Closest to daylight
- Best light for color rendering
- Color Temperature 3000K / CRI 100%
- 2,000 – 3,000 Hours
- Burns at continuous level of brightness
- When dimmed light turns more amber and orange

## LED MR & PAR

- LED CRIs continue to improve
- 3000K whites are crisp and colors vivid – without the yellow/orange of Halogen
- Green, blues, violets emphasized - Cool White
- Color Temperatures range from 2700-5000K / CRI 90%+
- 30,000-50,000 hours
- When dimmed maintains a consistent color temperature – No orange
- Less heat – No UV emitted

# Traditional Halogen / LED Applications



# Light-Emitting Diodes: LEDs



- Solid State Technology similar to computer chips emit light
- Visible light is generated by movement of electrons through the semiconductor material
- Different wavelengths of light are achieved by varying the semiconductor design
- Heat Sink is key component to removing internal heat and maintaining the quality of LED
- Three ways to produce white light

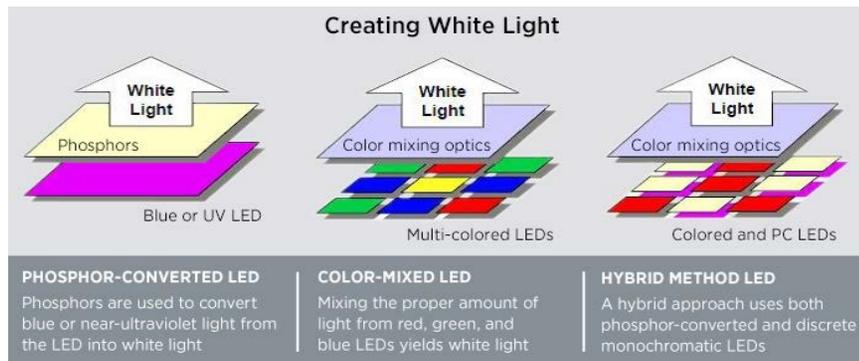
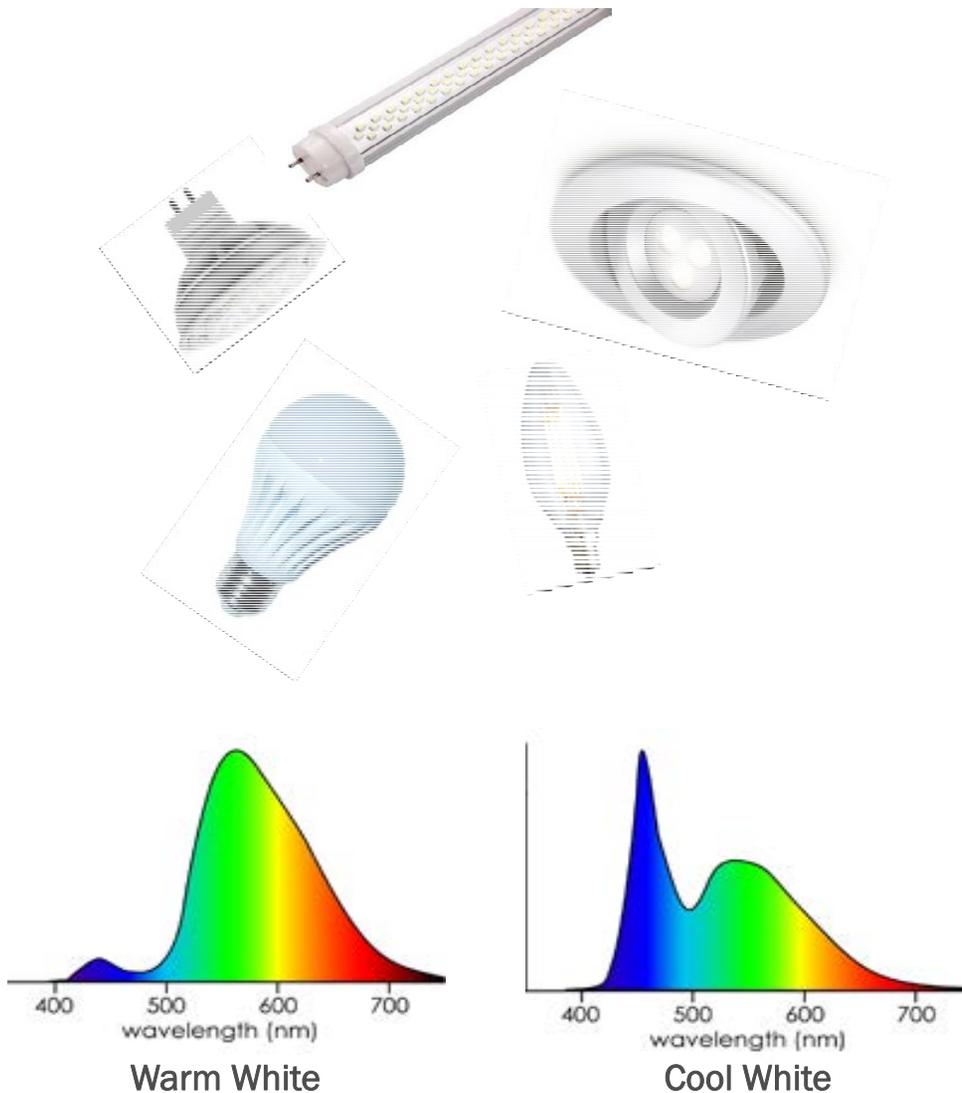


Image: Energy.Gov

# Light Emitting Diodes (LEDs)



## LEDs

- Warm whites are crisp and colors vivid
- Cool White, Green, blues, violets are emphasized
- Color Temperatures range from 2700K to 7000K / CRI 80% or higher
- Color Temperature remains relatively consistent when dimmed
- Minimal light loss / instant lighting
- Dimmable and controllable
- No mercury, UV, or IR
- Long Life 30,000-50,000 hours
- Energy efficient

# Lighting is changing: “Smart LEDs”

Behavioral Lighting  
*Set the Mood!*



Indoor  
Positioning



Light Therapy



## Purkinje Shift

Sensitivity to light

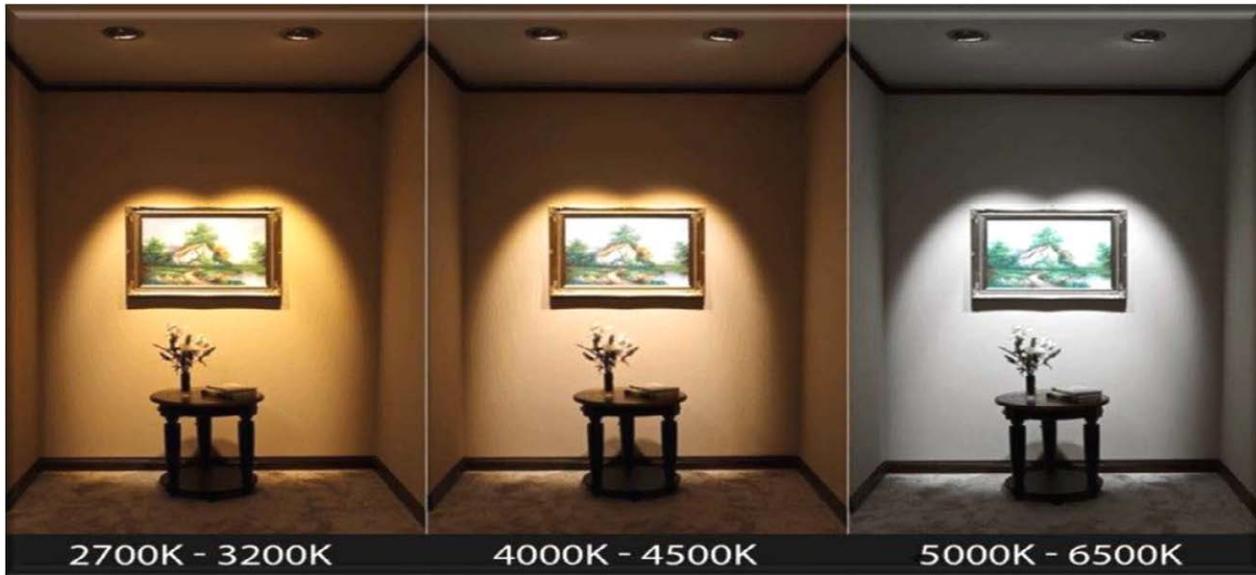
Sunny day: Red vibrant flower

Dusk: Dull and lacked contrast

## Purkinje Shift



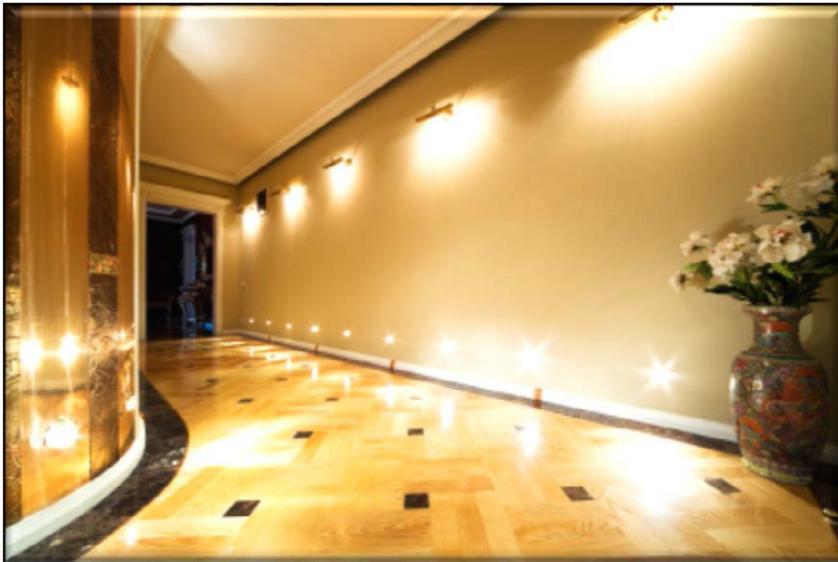
## Evaluate Colors Under Intended Light Source



Incandescent Compact Fluorescent Halogen / LEDs		Compact Fluorescent / Halogen Linear Fluorescent / LEDs			
~ 2700K	~ 3000K	~ 3500K	~ 4100K	~ 5000K	~ 6500K
Living Rooms Family Rooms Bedrooms  Commercial Hospitality	Living Rooms Family Rooms Bedrooms  Commercial Hospitality	Kitchen Bathrooms Basements  Commercial	Garage Basements  Commercial	Commercial Industrial Institutional	Commercial Industrial Institutional

# Reflectance and Paint Sheen

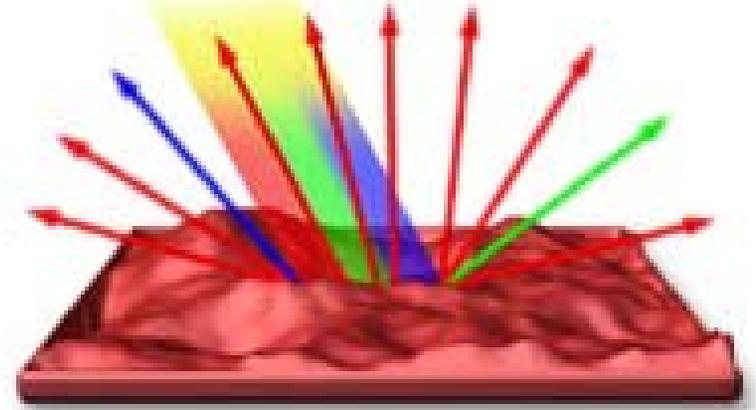
Satin / Semi-Gloss / Gloss



Matte / Flat / Eggshell

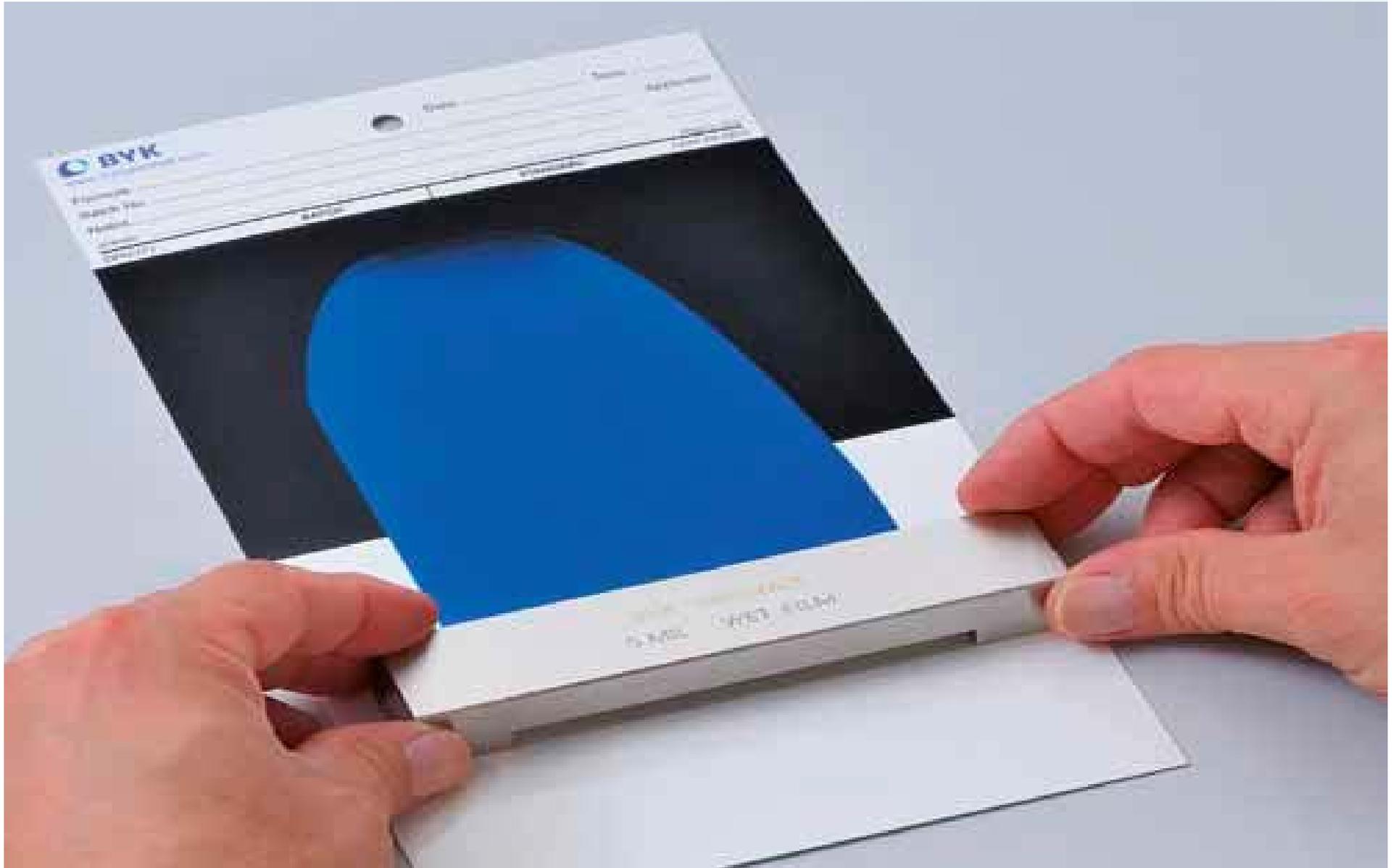


Specular Reflection



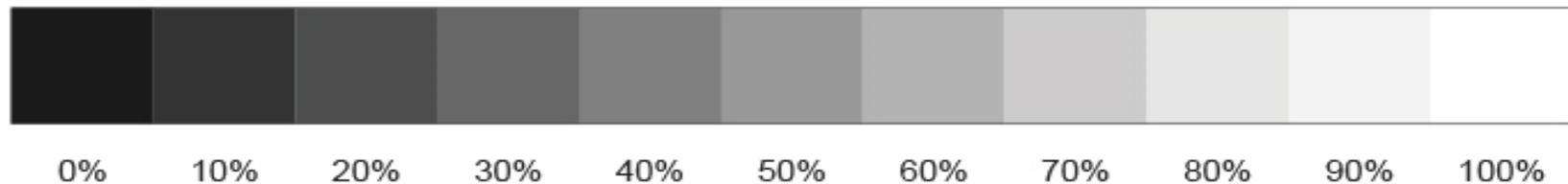
Diffuse Reflection

## Paint Draw Down



# Light Reflectance Value (LRV)

Light Reflective Value (LRV) Scale



Mid  
Range

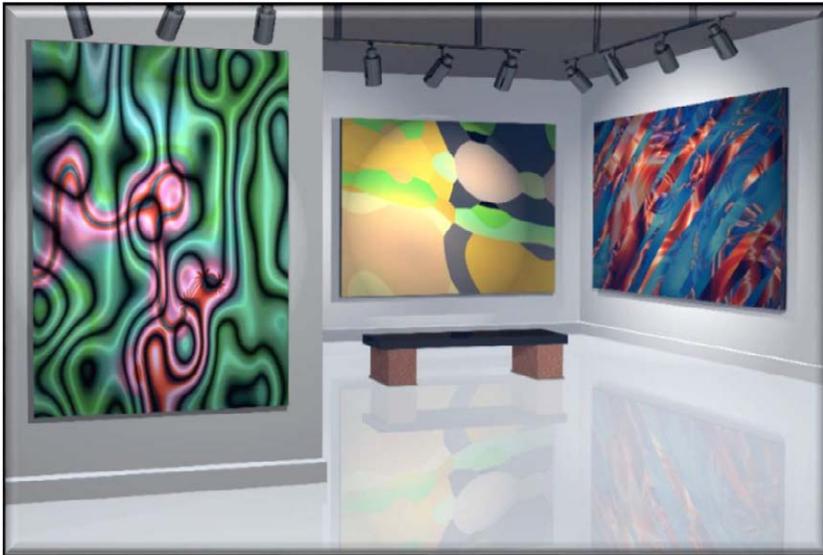
**Below 50%**  
Color is Darker  
Absorbing more light than it  
will reflect  
back in the room

**Above 50%**  
Color is Lighter  
Reflect more light back into  
the room  
than is absorbed

**LRV 10**

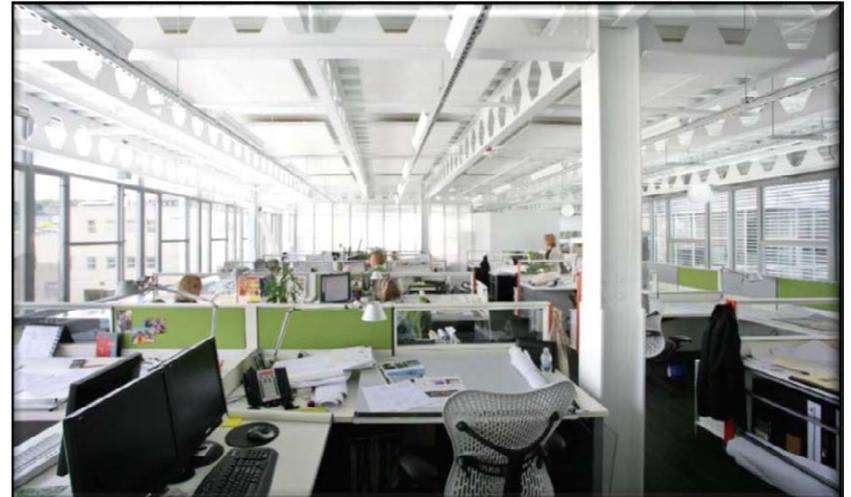
**LRV 84**

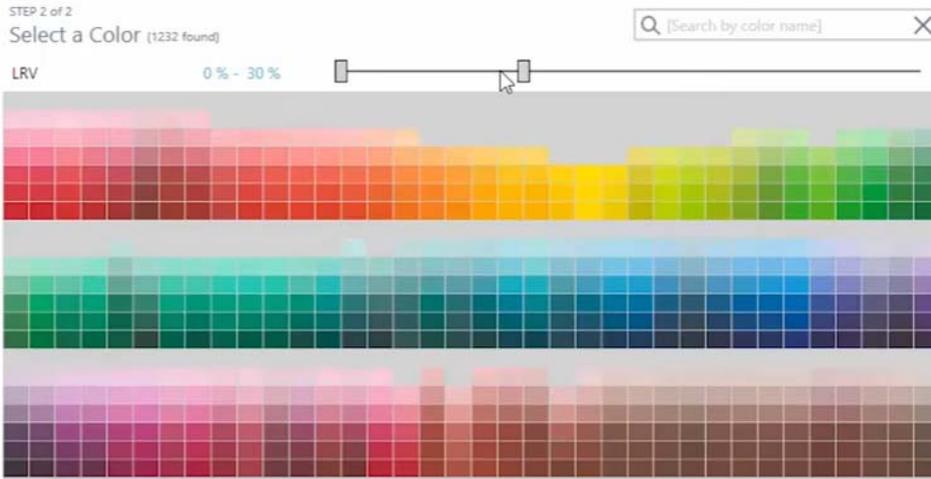
# Light Reflectance Value (LRV)



LRV Guidelines	
Residential	50%
Commercial Spaces	70%
Industrial Spaces	65%

*Yellows use with caution  
highly reflective*





Color Name	Number	LRV
Hunter Green	2041-10	5.5
Huntington Beige	HC-21	38.9
Hydrangea Flowers	2008-40	38.9
I Love You Pink	2077-70	79.6
Ice Blue	2052-70	85.9
Ice Mist	2123-70	90.1
Ice Mist	OC-67	90.1
Iceberg	2122-50	73.4
Iced Cube Silver	2121-00	74.2
Iced Mauve	2115-00	51.5
Iced Mint	2030-70	89.3
Iced Slate	2130-00	57.5
Icicle	2142-00	83.7
Icicle	OC-00	83.7
Icing on the Cake	2049-70	84.2
Icy Blue	2057-70	79.7
Icy Moon Drops	2056-70	85.9
Iguana Green	2028-10	30.1
Incense Stick	2115-20	7.4
Indian White	OC-88	77.5
Innocence	2055-70	81.8
Intense White	OC-51	74.4
Irish Clover	2038-20	15.8
Irish Mint	2041-70	85.6
Irish Moss	2036-20	16.9
Irish Spring	2038-70	86.7
Iron Mountain	2134-30	9.1
Iron Ore Red	2089-10	14.5
Italian Ice Green	2035-70	83.7
Italiano Rose	2087-30	19.9
Ivory Tower	2157-70	89.0
Ivory Tusk	2153-70	87.2
Ivory Tusk	OC-91	87.2

## Manufacturer's Website

### Bavarian Cream

LRV: 89



#### Light Reflectance Value

LRV, or Light Reflectance Value, is a measurement commonly used by design professionals—such as architects and interior designers—that expresses the percentage of light reflected from a surface. LRVs range from 0-100, with 100 being pure white and 0 being absolute black.

- LRVs can be found on fan decks
- Paint Manufacturer's website
- Revit Color Suite Apps

# Metamerism





## Types of Metameric Failure

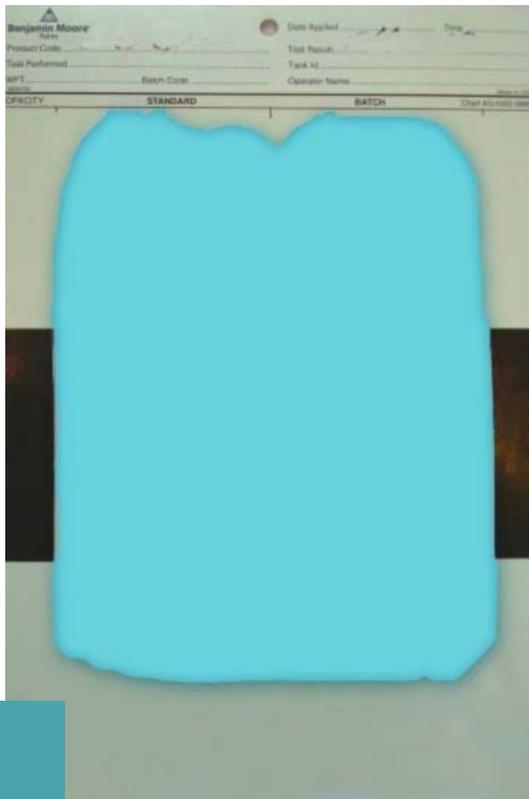
Geometric

Observer

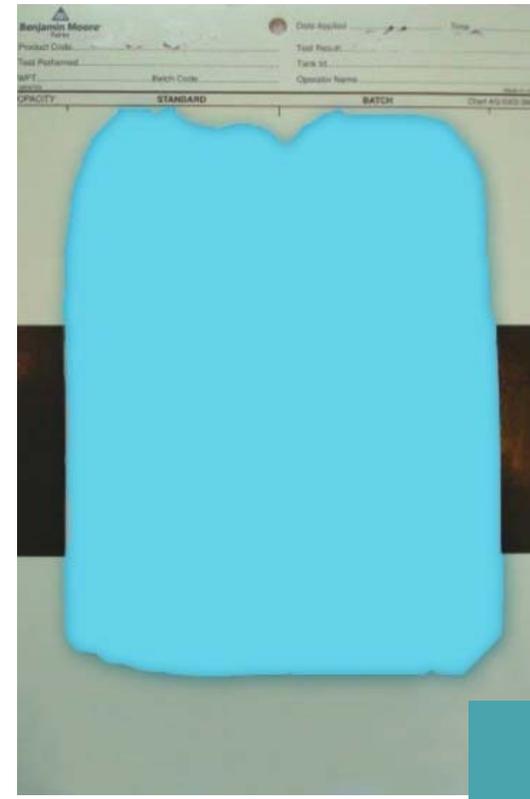
Field Size

# Illuminant Metameric Failure

When viewed under  
Incandescent Light  
both samples match.



When viewed under  
Fluorescent Light, both  
samples DO NOT match.



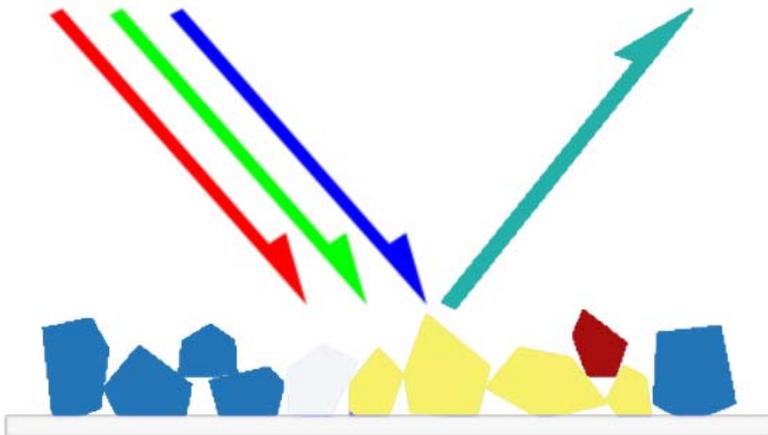
# Illuminant Metameric Failure

## Color Prescription

Thalo Blue  
Titanium White  
Organic Yellow  
Iron Oxide



Control  
Sample

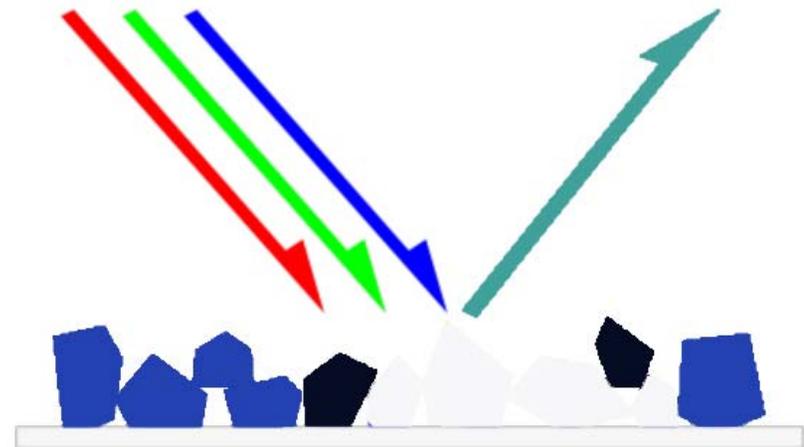


## Color Prescription

Synthetic Ultramarine  
Titanium White  
Lamp Black



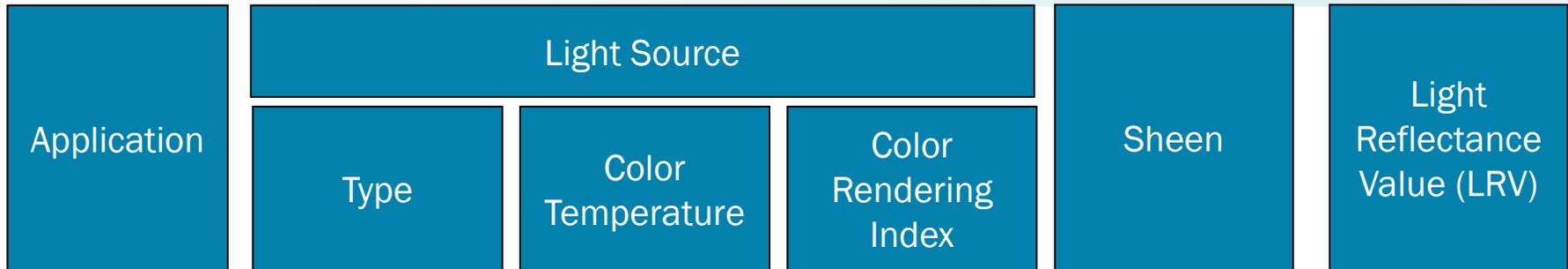
Match  
Sample



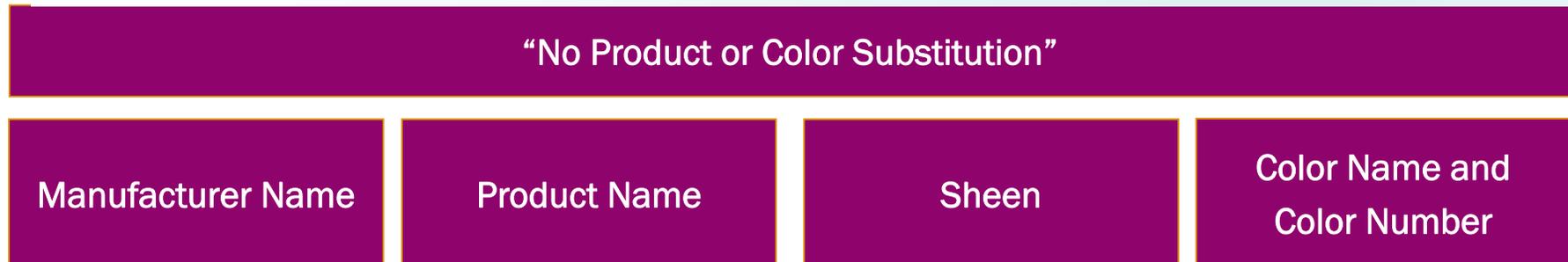
## Specification

- Manufacturer's base paint, colorants and color prescriptions are not the same
- Undertones in colorants are impacted by color temperature
- Specify Manufacturer, Product and Color
- Indicate NO product substitution and NO color matching

## What to consider when selecting a paint color



## Indicate on your specification





## Summary

- The role of light and the process that occurs between the brain and the eye to see and perceive color.
- Differentiate between various types of light sources and how the color temperature and color rendering index can influence the color in the space.
- Demonstrated how a color's LRVs can make the most of available daylight - decreasing the reliance on artificial light sources.
- Identified important considerations when selecting a Paint Color (Application, Light Source, LRV, and Sheen).
- And finally, why a manufacturer's paint, colorants and color prescriptions can not be matched



Thank you!

# BENJAMIN MOORE ADVANTAGE Exclusive Gennex<sup>®</sup> Waterborne Colorants

- Industry leading technology
- Proprietary resin
- Rich colorants
- Fortifies the paint
- Maintains consistent viscosity across bases
- Improves paint performance & application
- Any color - low VOC
- Environmentally friendly



# Resources

Energy.Gov. Office of Energy Efficiency and Renewal Energy. History of the Light Bulb. 22 Nov 2013. Accessed 12/5/2016 <http://energy.gov/articles/history-light-bulb>

Rutgers School of Arts and Sciences. Thomas Edison Papers. 28 Oct 2016. Accessed 12/5/2016. <http://edison.rutgers.edu/lamp.htm>

ABCs of LEDs. 2016 Update. Accessed 12/5/2016. <http://www.bdcuniversity.com/archived-ceu-webinar-led-lighting-301-abcs-led-2016-update>

AboutMoney. Mary Bellis. History of Lighting and Lamps. Accessed 12/5/2016. <http://inventors.about.com/od/Istartinventions/a/lighting.htm>

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