Lighting Measurements

A basic approach to understanding the principals of Lighting Science

Developed and Narrated by Nlena and Associates, Inc.

Lighting Science

A hand out of this Presentation is available for download on the IES Education website.

(1)IES CEU certificate of attendance will be available for viewing this presentation.

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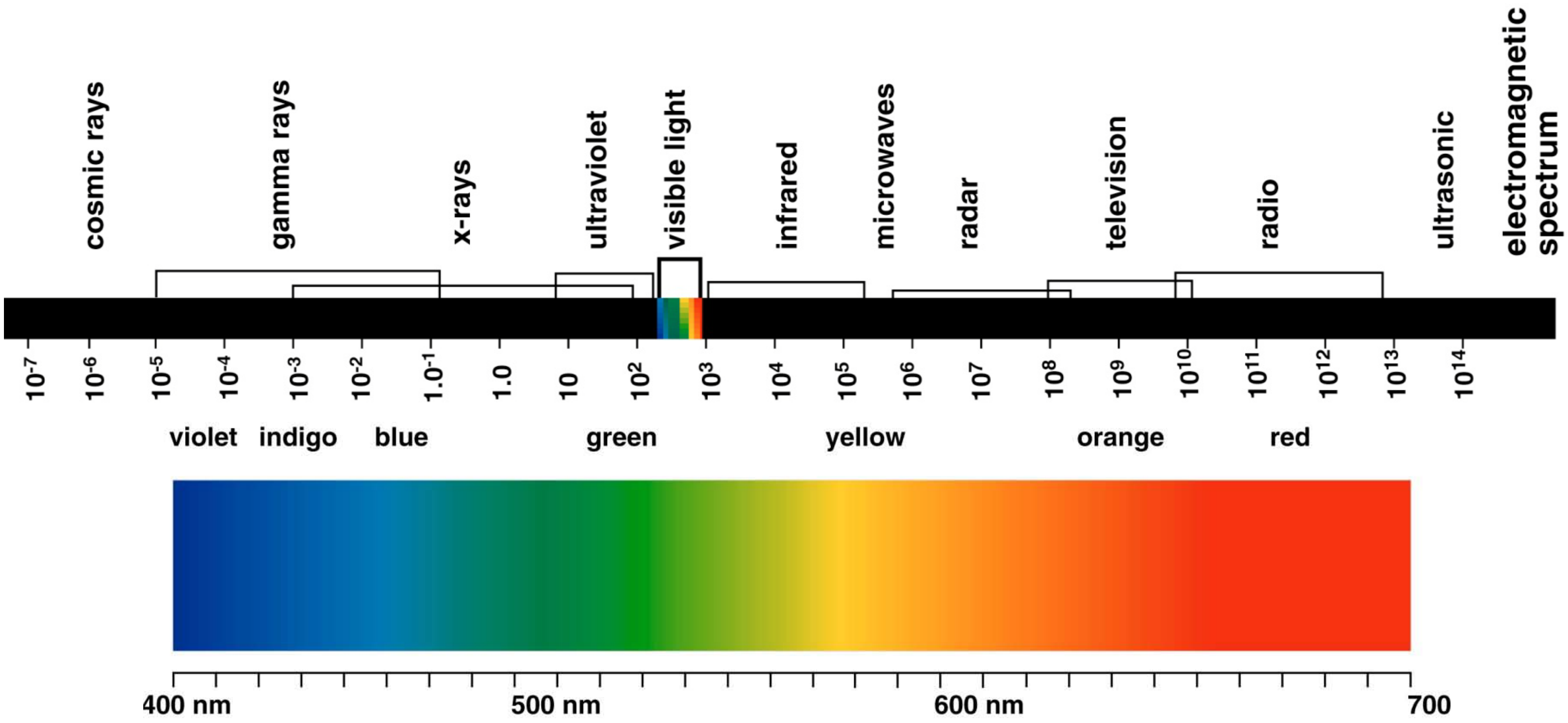
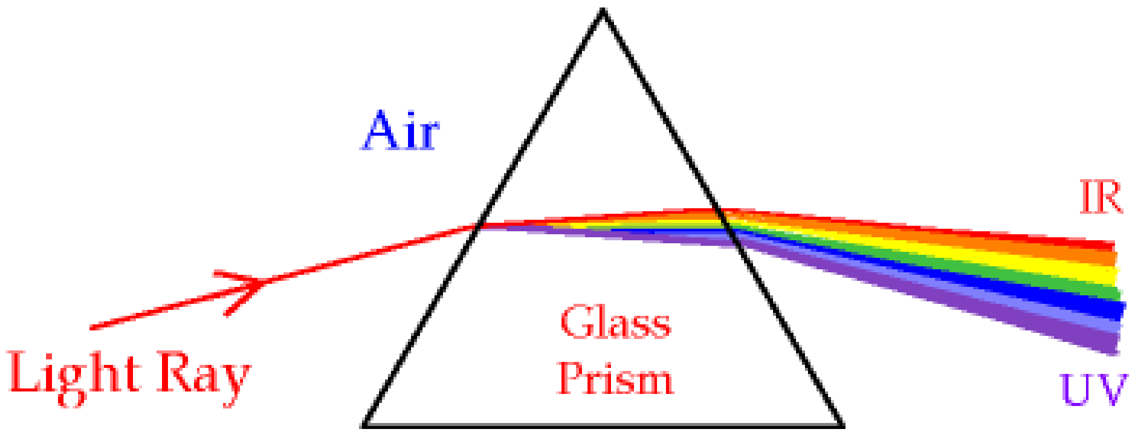
Electromagnetic Spectrum



Velocity of Light = (wavelength) x (frequency)
(meters) x (cycles per second or Hertz)

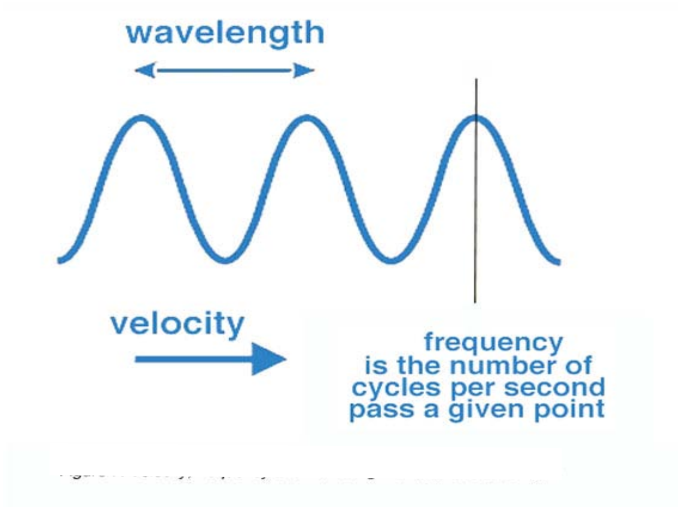
(3 x 10^8 m/sec)

Light Energy

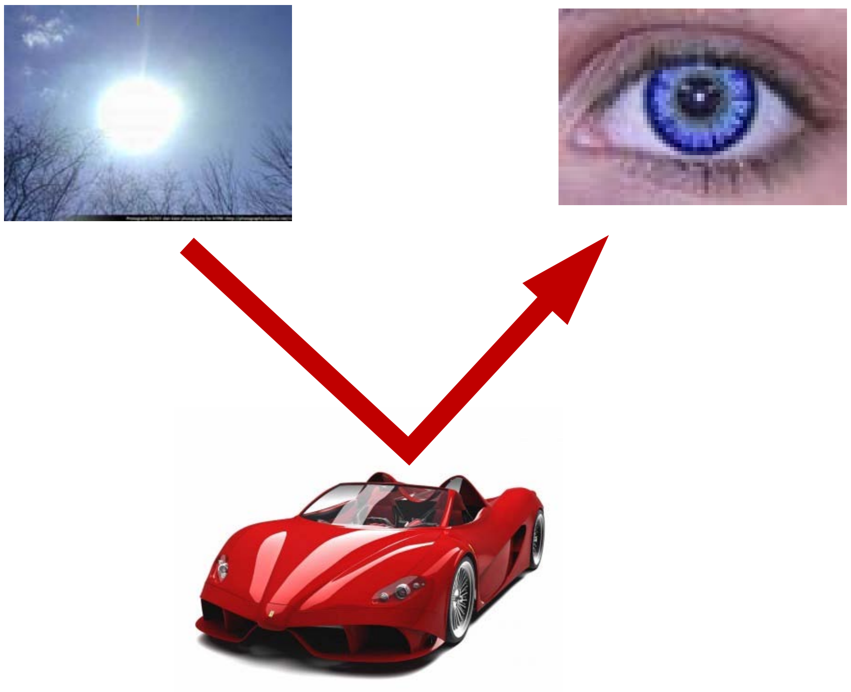


White light is dispersed into its component colors by refraction.

The angle of deviation varies with wavelength.



Light and Color Perception



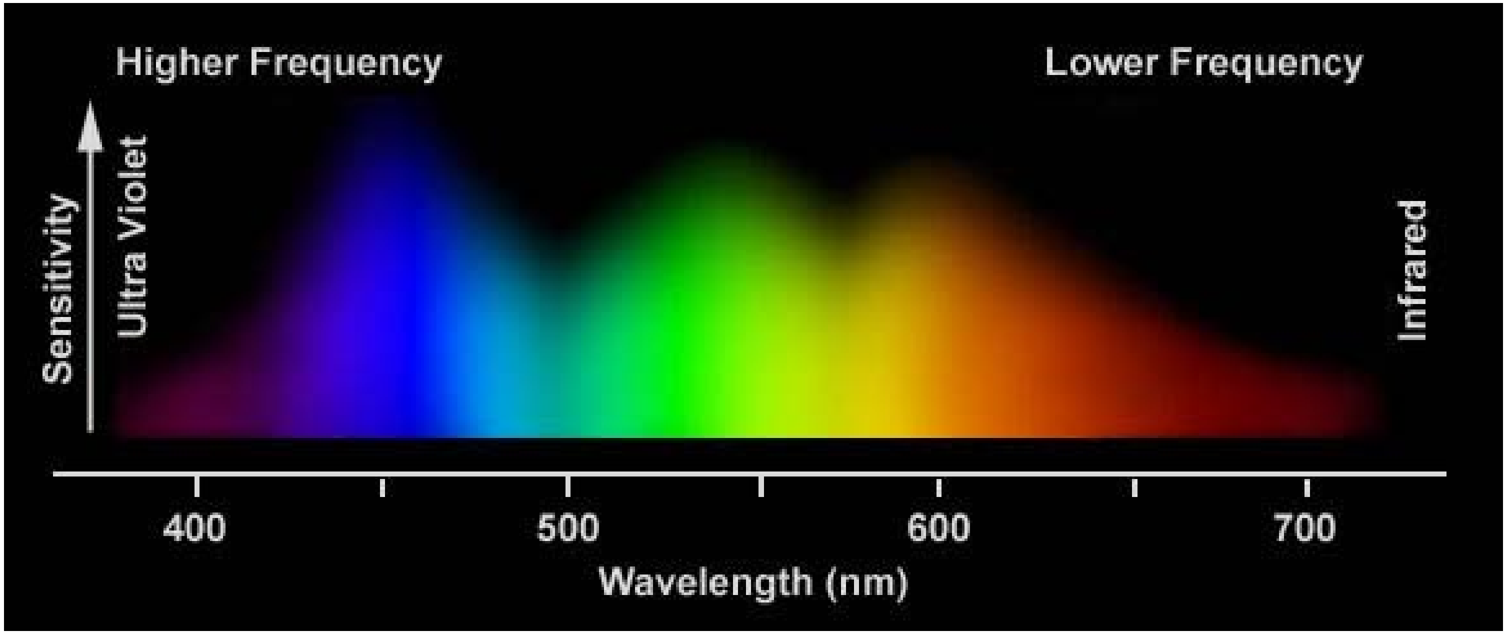
Observer Situation

Three basic parts are required to provide us with Light and Color Perception

- light source
- object being viewed
- observer (person)

Light and Color Perception

•Typically characterized as Red, Green and Blue receptors, it would be far more accurate to describe observer sensitivity as short , medium and long wavelength responses.



Common Light Sources

Daylight

Incandescent

LED

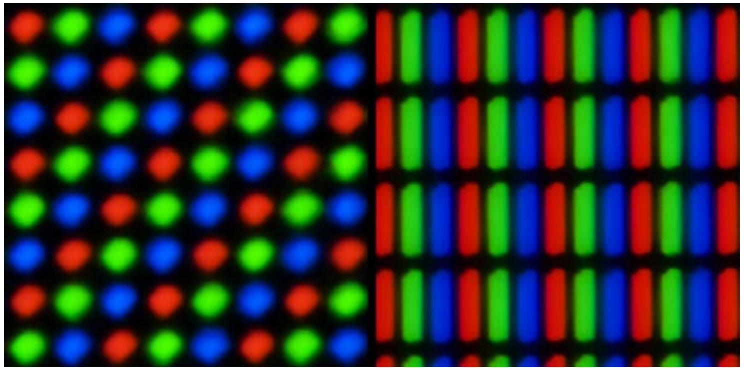
Horizon Daylight

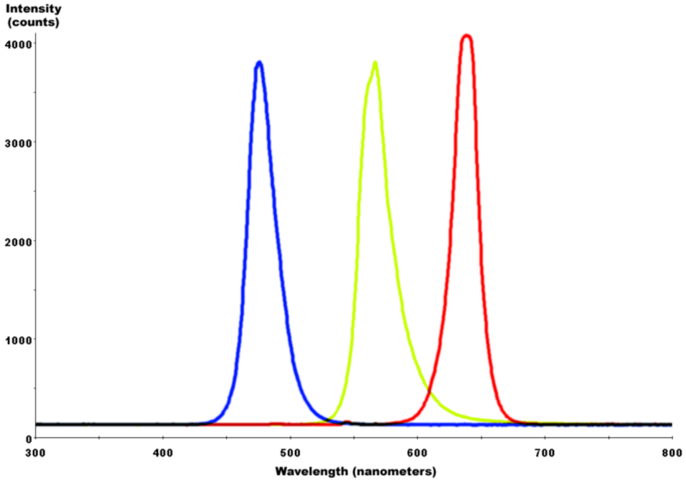
Fluorescent

HID

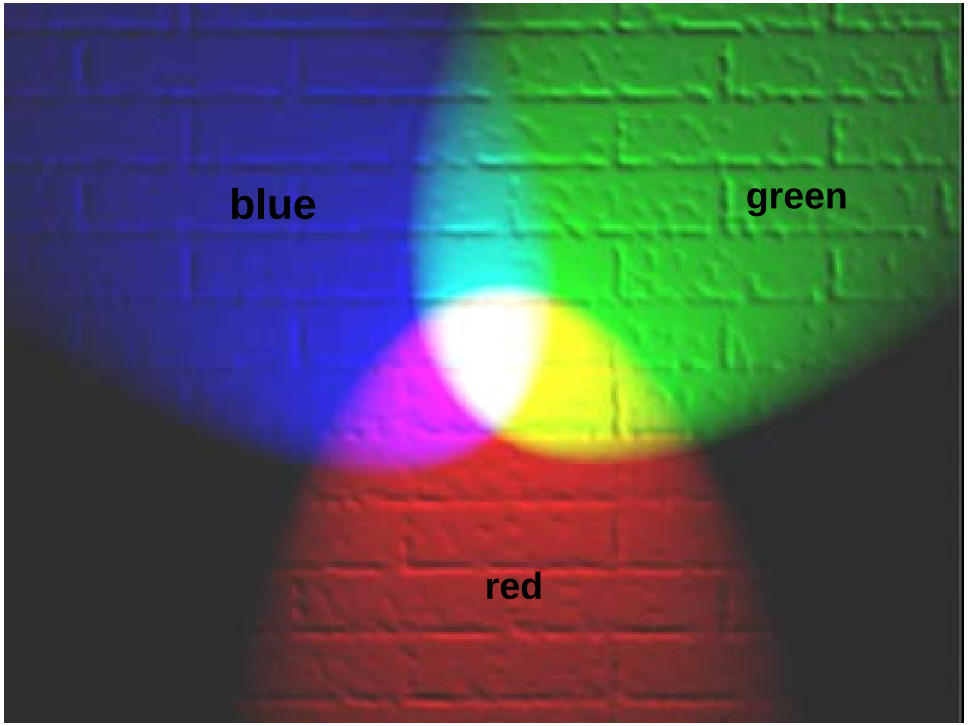
Light Measurement

LED Technology



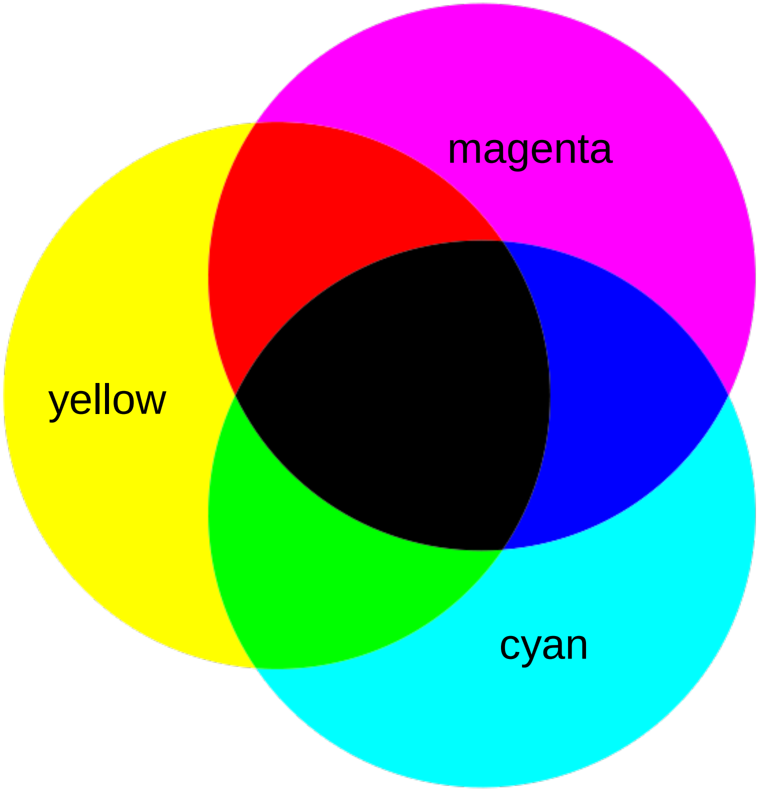


Color Models



Additive Principals (Light)

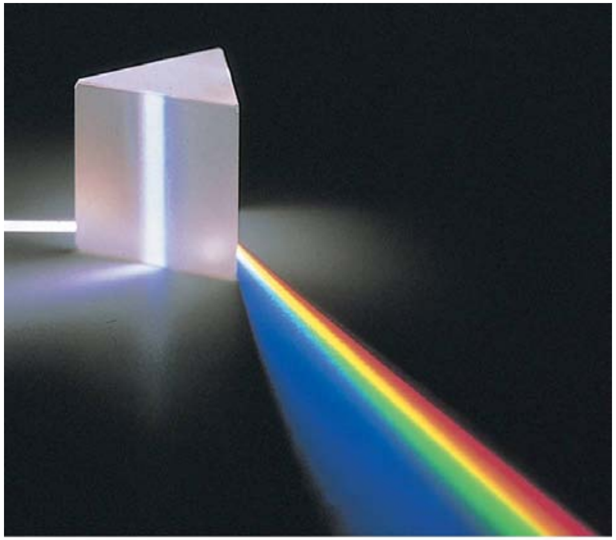
Color Models



Subtractive Principals
(Dyes and Pigments)

Illuminating ENGINEERING SOCIETY

Light Measurement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The use of filters, prisms, holographic gratings, photo multiplier tubes, monochrometers, charged coupled devices and photo diode arrays can all be used with varying degrees of accuracy to characterize the spectral content of a light source.

Light Measurement

Many systems and methods have been devised to quantify light sources so that communication of color would become easier and more accurate. These methods attempt to provide a way of expressing a light sources color and energy output and tolerances numerically, in the same way we express length and weight. In some of our follow up discussions we will discuss some of these metrics in more detail. Some of these include:

•Chromaticity coordinate color spaces (1931 CIE, 1964 CIE UCS)

•MacAdam Elipses

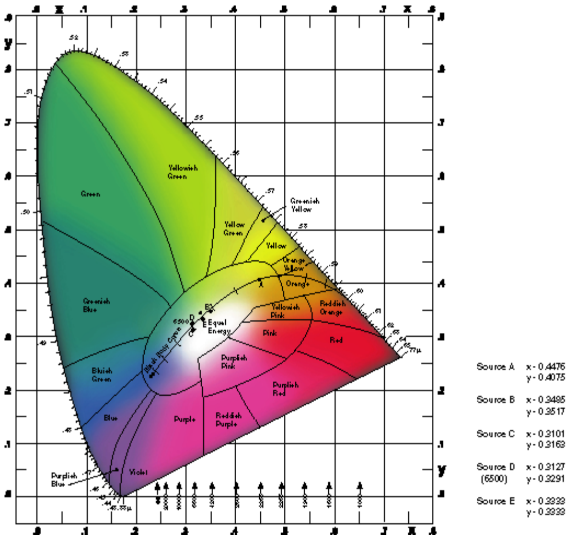
•Luminance and Illuminance Values

•Correlated Color Temperature

•Standard Illuminants

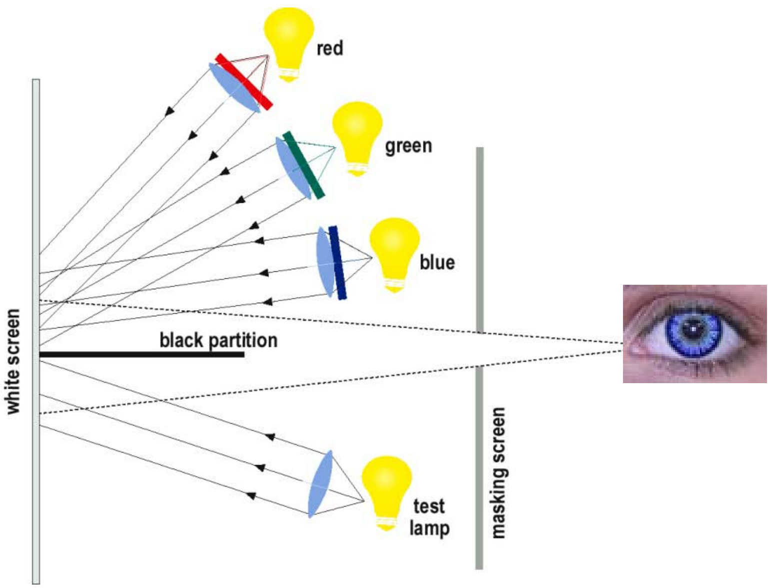
•Spectral Power Distribution

•Color Rendering Index



Light Measurement

CIE Standard Observer Experiment



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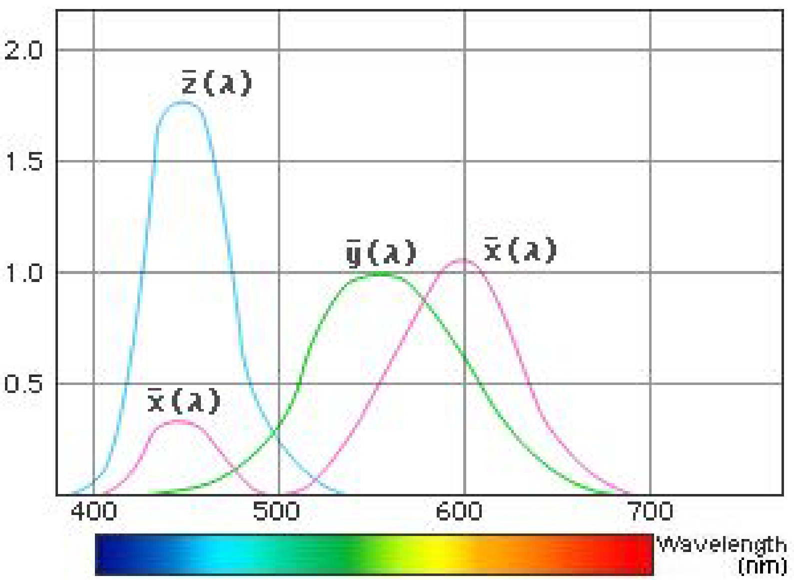
Standard Observer Response

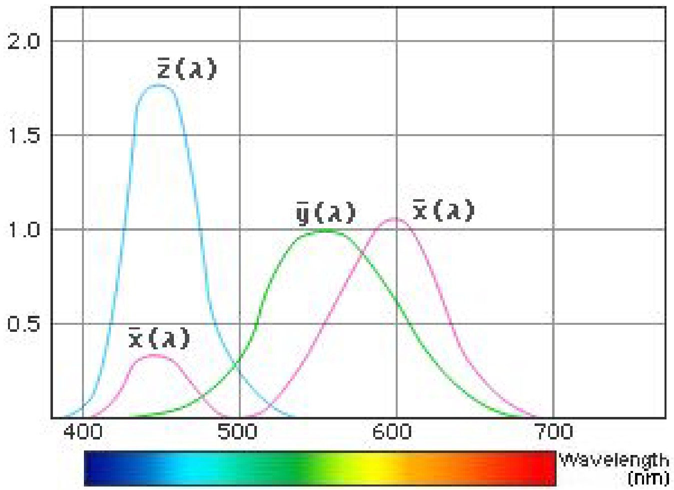


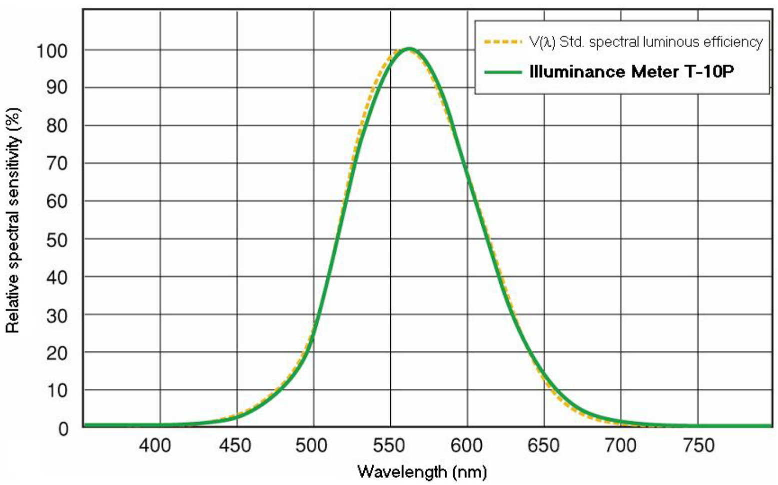
Light Measurement

Photometry

Photometry involves the physical measurement of visible light energy and attempts to compensate for the psychophysical attributes of the human response and physical units of power.

Photometry is just like radiometry except that everything is weighted by the spectral response (luminosity function) of the human eye as defined by the CIE.



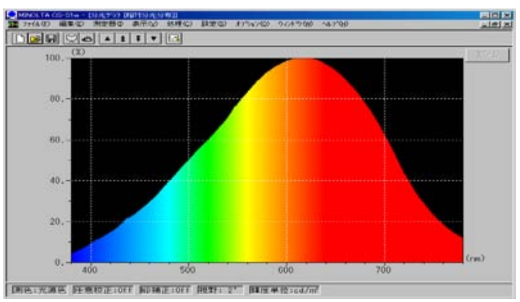


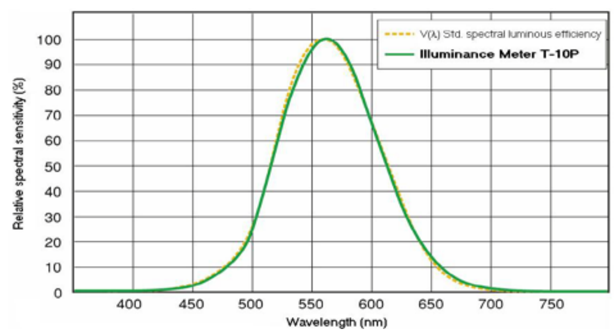
Light Measurement

Photometry

The photometric quantity, Luminance, Illuminance are derived from the corresponding radiometric quantity, Radiance, and the CIE Standard Luminosity Function. We can think of the luminosity function as the transfer function of filters which approximate the sensitivity of the human eye.

Radiometric Quantity → CIE Standard Luminosity Function ($V\lambda$) → Photometric Quantity





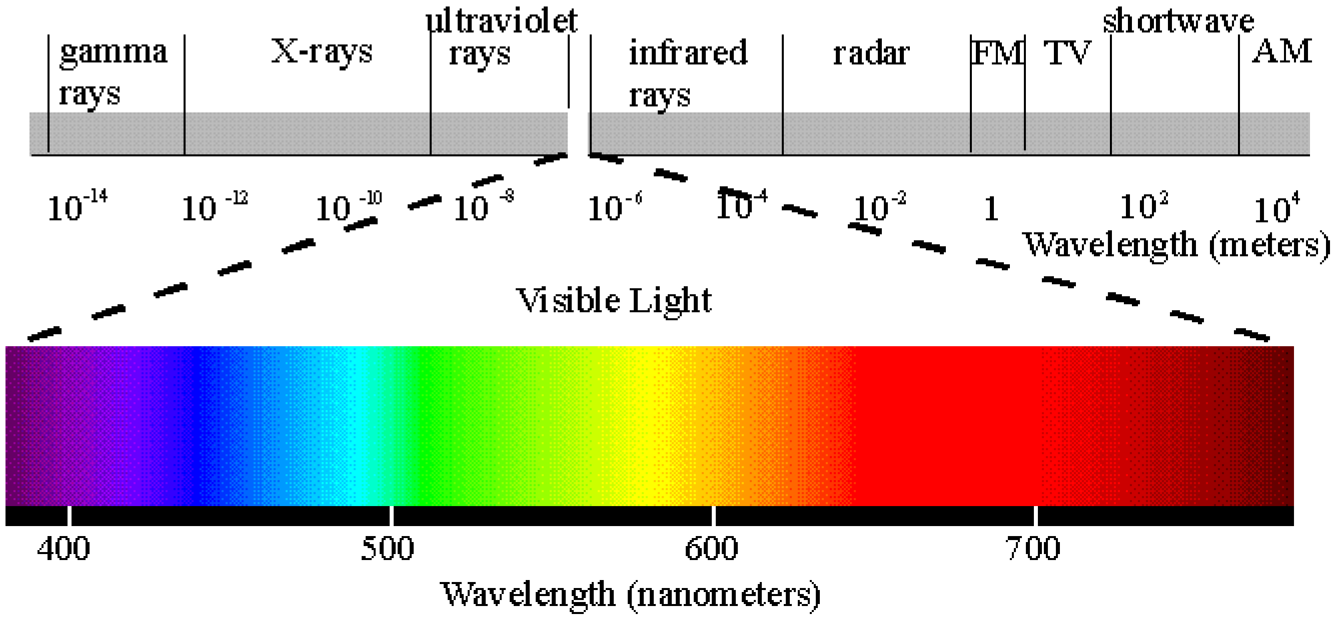
Example:
Luminance: 15cd/m^2
Illuminance: 500lx

Relationship between radiometric units and photometric units

Light Measurement

Radiometry

Radiometry is the science and measurement of energy or electromagnetic radiation. It is the measurement of the physical properties of light energy and may include ultraviolet, infrared energy or specific wavelengths.



Light Measurement

Photometry versus Radiometry

	Radiometry		Photometry (380 – 780 nm widely used)	
Quantity	Radiometric Term	Radiometric Term	Photometric Term	Photometric Term
Power	Radiant Flux	Watt (W)	Luminous Flux	Lumen (lm)
Power per Unit Solid Angle	Radiant Intensity	W/sr	Luminous Intensity	lm/sr = candela (cd)
Power per Unit Area	Irradiance	W/m^2	Illuminance	lm/m^2 = Lux (lx) lm/ft^2 = Footcandle (fc)
Power per Area per Solid Angle	Radiance	$W/m^2/sr$	Luminance	$lm/m^2/sr = cd/m^2$ = Nit $lm/ft^2/sr = cd/ft^2$ = Fl

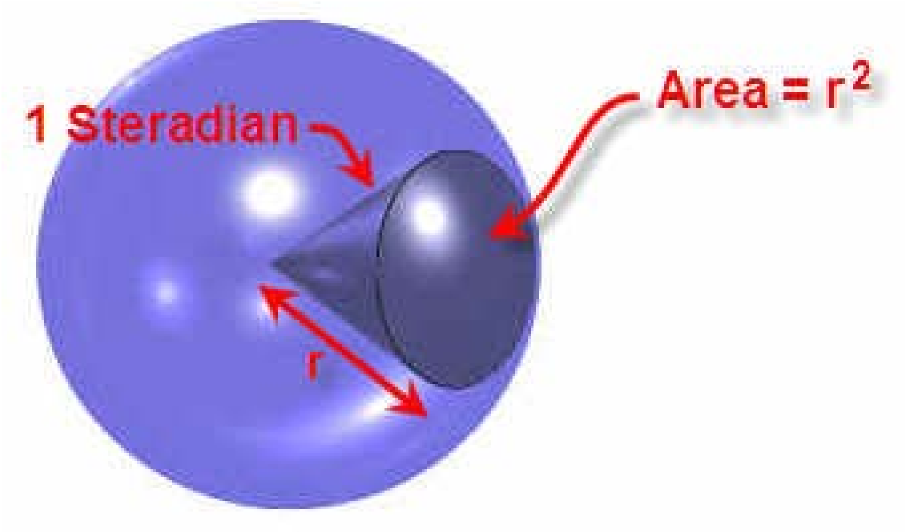
Light Measurement

Steradian

A unit of measure, sr, equal to the solid angle subtended at the center of a sphere by an area on the surface of the sphere that is equal to the radius squared: *The total solid angle of a sphere is 4π steradians.*

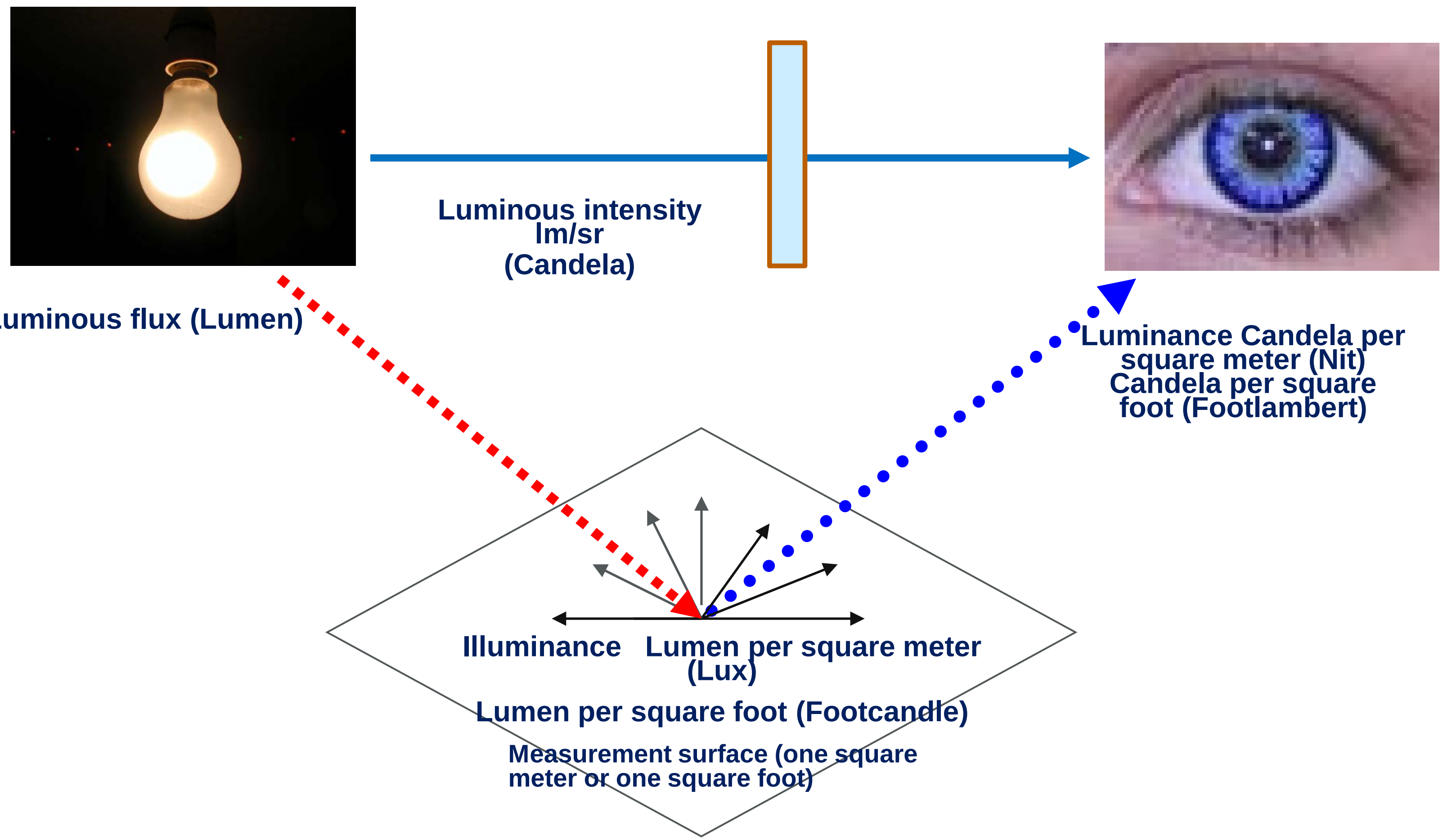
Radiometric values such as radiant intensity are measured and stated as watts per steradian.

($W \cdot sr^{-1}$)



Light Measurement

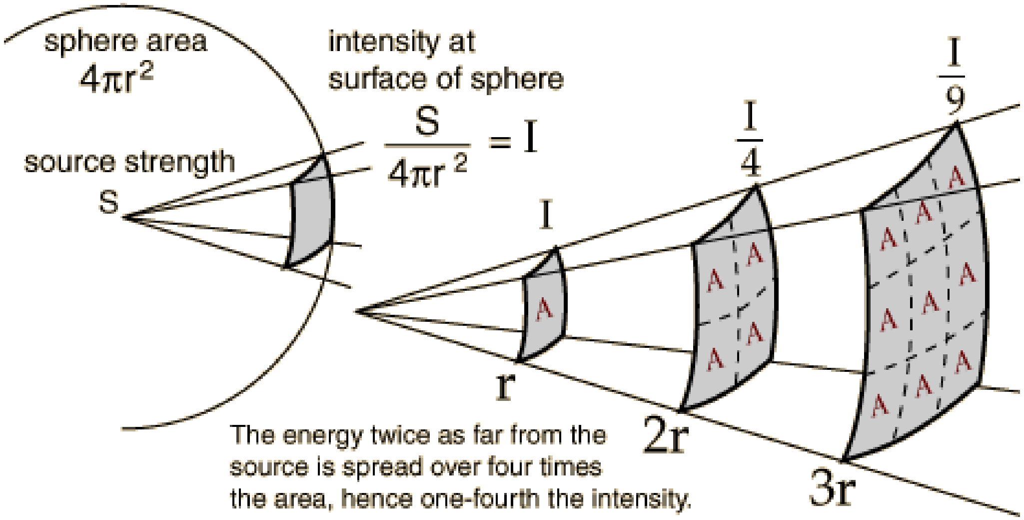
Overview of Photometric Quantities



Light Measurement

Inverse Square Law

Any point light source which spreads energy in all directions will behave in accordance with the **Inverse Square Law**. This law is based strictly geometrical considerations. The intensity of the light source at any given radius r is the source strength divided by the area of the sphere. Being strictly geometric in its origin, the inverse square law also applies to gravitational force, electric fields, light, sound or radiation and all obey the inverse square law.

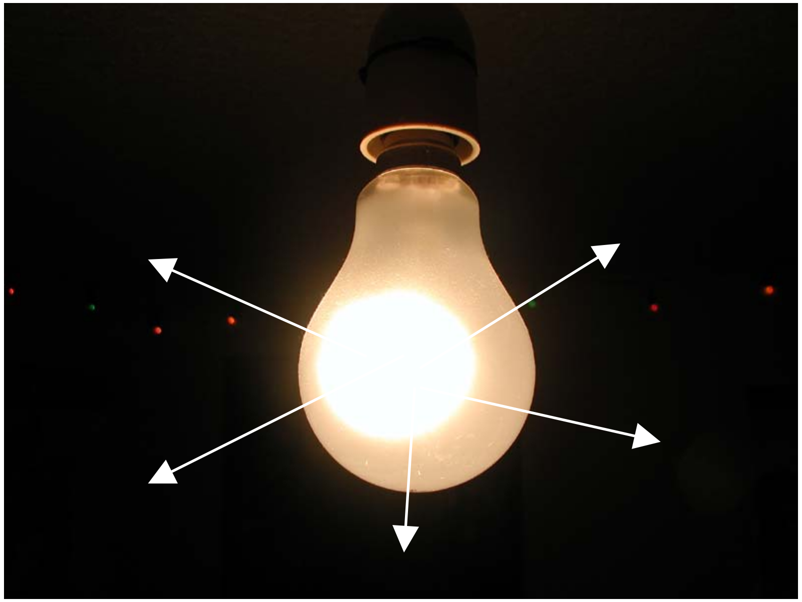


Light Measurement

Brightness is the attribute of a light source that is perceived when the source seems to emit more or less luminous flux per unit area.

Luminous Flux is the flow of light from a source per unit of time and is measured in Lumens.

Luminous Efficacy of a light source is a measure of the efficiency of the lamp to produce lumens per watts of power consumed.



Total Luminous Flux is emitted in Lumens (860 Lumens)

Power is consumed in watts per unit of time (60 watts)

860 / 60 =14.30 Lm/Watt

Light Measurement

Instruments

There are two broad classifications of light and light source color measuring instruments.

•Direct reading Tristimulus instruments commonly called 3 or 4 filter Colorimeters or Photometers.

and

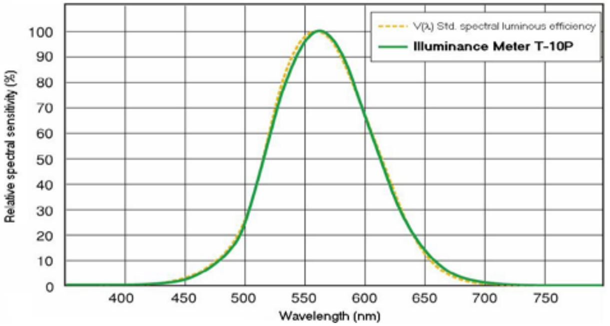
•Spectrally Based instruments called Spectroradiometers.

Light Measurement

Filtered Colorimeter / Photometer

Instruments designed for measuring the color of light, which use three or four filters with a spectral sensitivity matched to the CIE Tristimulus color matching functions, is known as filter colorimeter.

Beside chromaticity measurements, these meters usually include one of the 4 basic photometric measurements such as luminance, illuminance, luminous intensity, or luminous flux.



These instruments use a detector, typically high quality photodiodes with series-connected filters. The incident light is converted by the detector into signals which directly yield the standard XYZ Tristimulus values.

Light Measurement

3 or 4 Filter Colorimeter

Light source

Receptors

x response
y response
z response

X
Y
Z

Processor

= 21.21
= 13.37
= 9.32

Values

Tristimulus Values, X,Y and Z are calculated by the microprocessor and can be used to calculate values in other color spaces.

Sensors and filters simulating the color response of the human eye, RGB.

Light Measurement

Short falls of Filter Colorimeter

Matching to the standard CIE Tristimulus curves can be achieved only with finite accuracy. Deviations can occur between defined CIE curves and sensitivity curves in the measuring instrument.

These differences are negligible as long as the light to be measured exhibits a continuous energy output over the entire visible spectrum. However, the error may be significant if steep edges, mercury emission spectral lines occurs in the spectrum.

Three or Four filter colorimeters are not usually suited to measure light sources with spectral lines (discharge lamps) or with narrow spectral energy distributions as found in Narrow Band or Tri-Band Fluorescent and LEDs.

A filter based photometer cannot determine radiometric and spectral quantities or calculate metrics like color rendering index.

They should be used for QC applications and relative comparisons.

Light Measurement

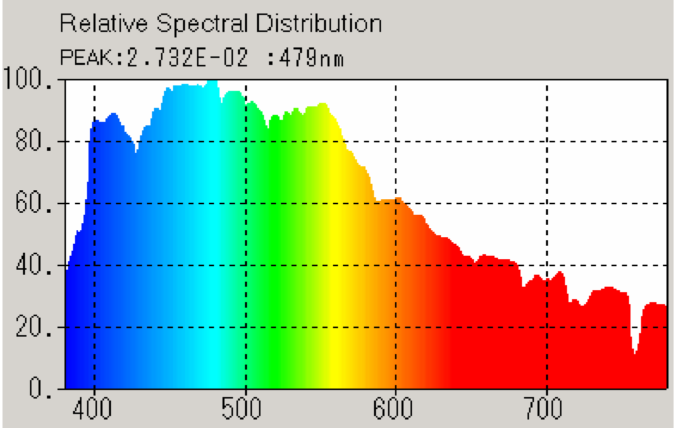
Spectroradiometer

Spectroradiometers are the most accurate for measuring spectral energy distribution of any light source. They are used for determining not only the radiometric and photometric quantities, but also the colorimetric quantities of a light source.

Spectral data is used to calculate the CIE Tristimulus values by mathematically integrating the data with the CIE x(λ), y(λ), z(λ) functions.

The Tristimulus values are then used to compute CIE chromaticity coordinates and luminosity, which provide a complete description of the color including chromaticity spectral power, illuminance and luminance.

Dispersion of light is usually accomplished in Spectroradiometers by means of prisms or diffraction gratings.

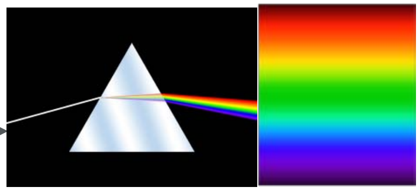


Light Measurement

Spectroradiometer

Light source

Prism or Diffracting Grating



Receptor

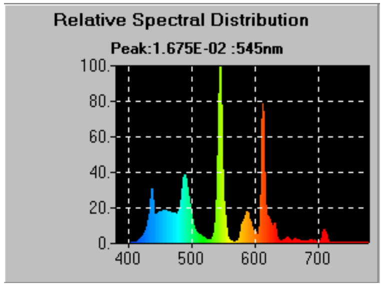
Spectral Photo Diodes , Photo Multiplier Tubes, PMT , Charged Coupled Devices, CCD or Detector Arrays, sensitive to a specific wavelengths.

Processor

Value and Graphs

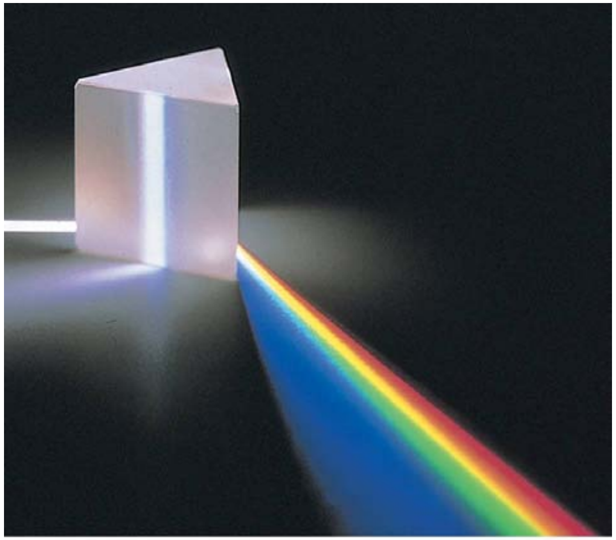
Tristimulus Values, X,Y and Z are calculated by the processor and can be used to calculate values in other color spaces.

Spectral Power



Light Measurement

Visible Light Energy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The use of filters, prisms, holographic gratings, photo multiplier tubes, monochrometers, charged coupled devices and photo diode arrays can all be used with varying degrees of accuracy to characterize the spectral content of a light source. The graphic representation of the relative power at each wavelength is referred to as Spectral Power Distribution, SPD.

SPD data and graphs are one of the most powerful tools for determining the spectral content of a light source. Measurements can include UV and IR energy and very small band pass increments of 1nm or less.

Light Measurement

Spectroradiometer

The exact **CIE Vλ** curve and CIE color matching functions are stored in the software and used to process the data from the measured spectral power distribution of the light source.

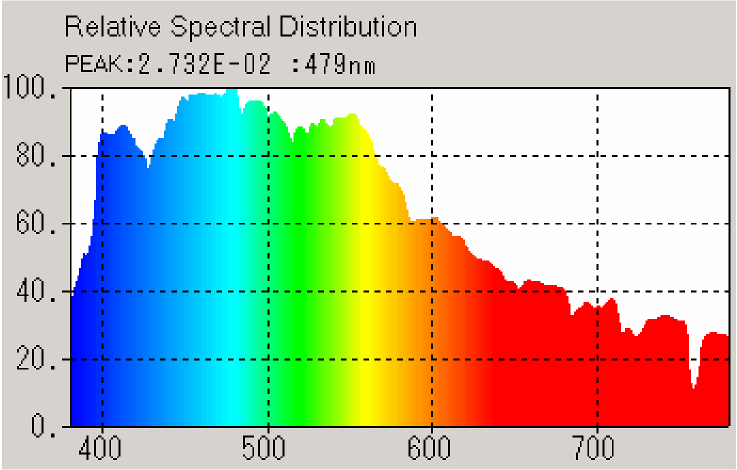
Measurement error associated with photometers and filter colorimeters is avoided in Spectroradiometers by using wavelength correction and various emission energy calibration techniques.

Adequate sensitivity, high linearity, low stray light, low polarization error, and a spectral band pass resolution of 1 nm or less can be achieved providing improved accuracy.

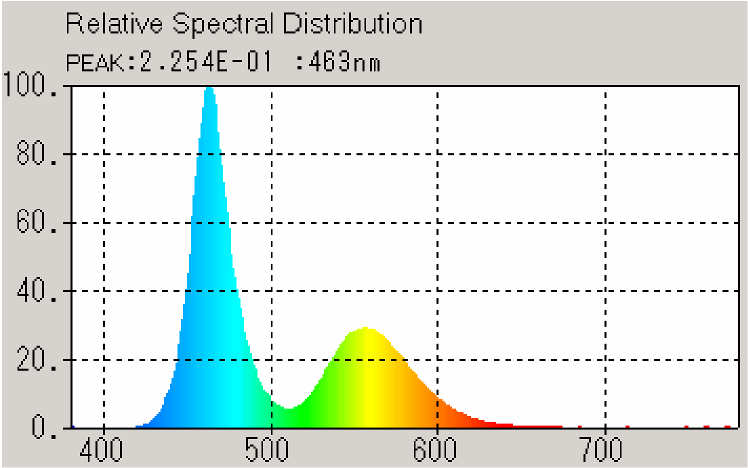
Spectroradiometers do have some limitations in terms of speed measurement, price and system portability.

Light Measurement

Spectral Radiance (Spectral Power Distribution) SPD



Daylight

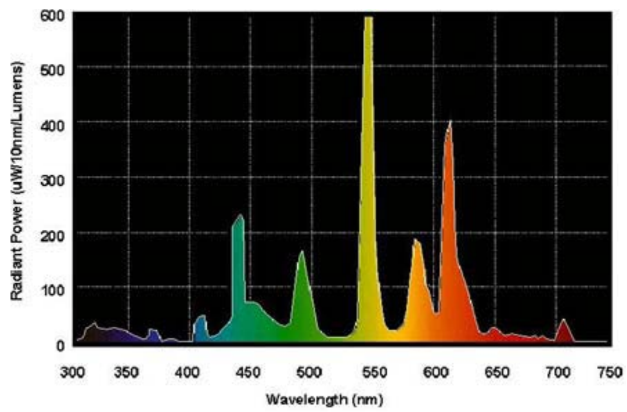


White LED

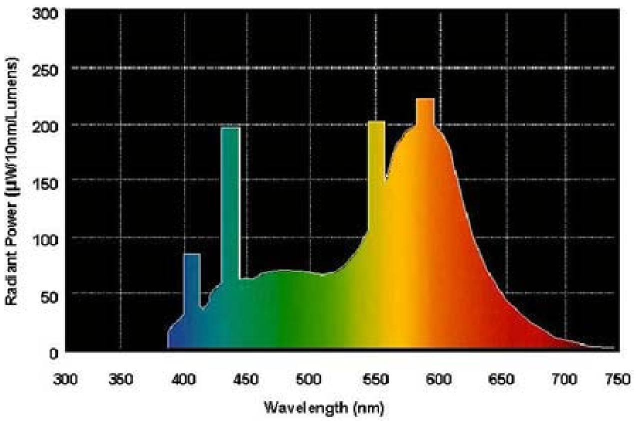
The graphic representation of the relative power at each wavelength is referred to as Spectral Power Distribution, SPD.

Light Measurement

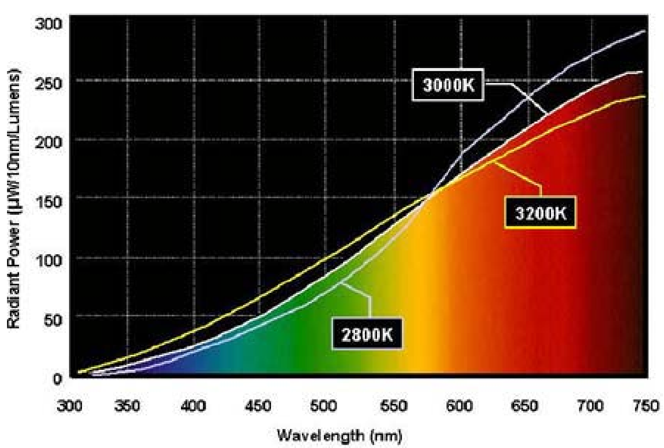
Spectral Radiance (Spectral Power Distribution) SPD



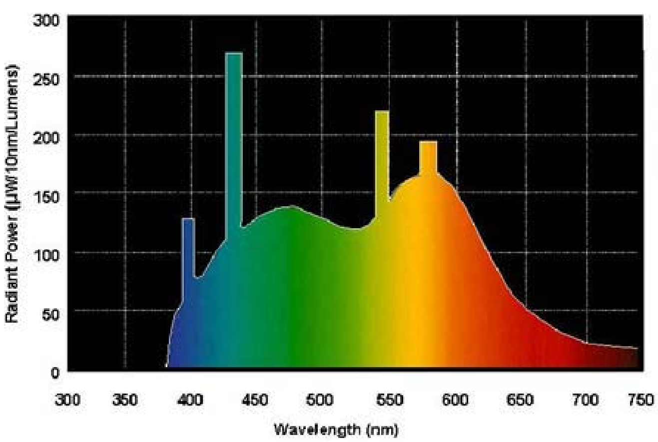
Narrow Band Fluorescent



Wide Band Fluorescent CWF



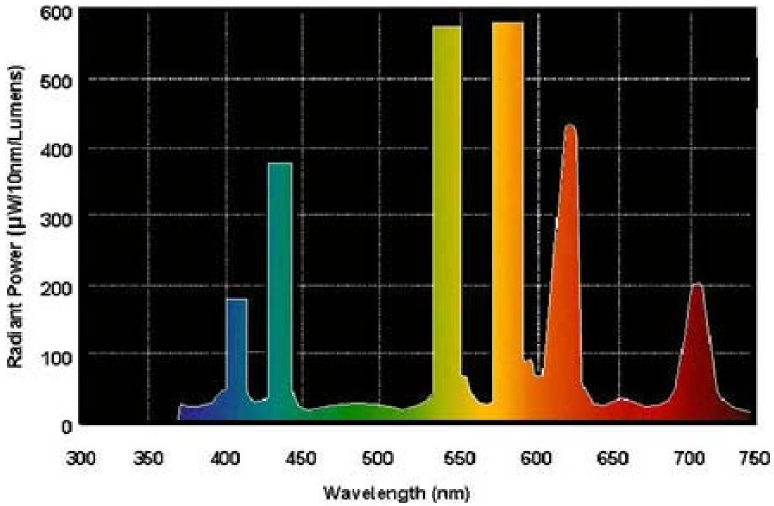
Incandescent, Halogen



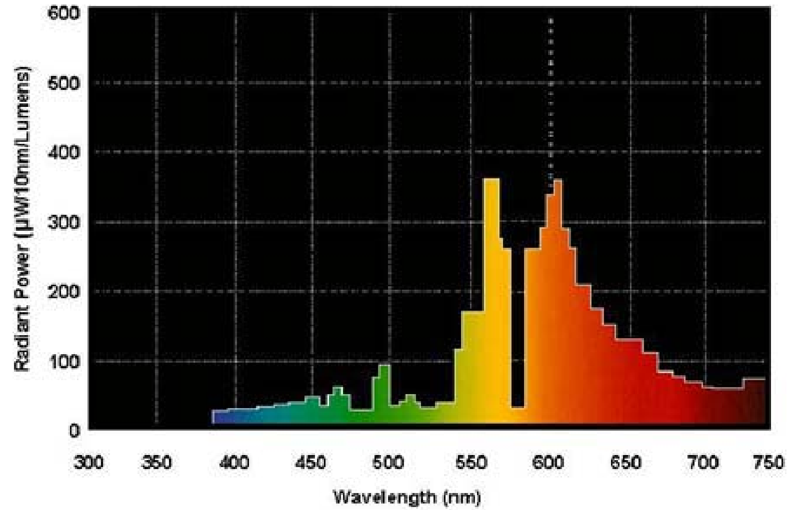
Daylight Fluorescent

Light Measurement

Spectral Radiance (Spectral Power Distribution) SPD



Deluxe White Mercury



Deluxe High Pressure Sodium

SPD data and graphs are one of the most powerful tools for determining the spectral content of a light source. Measurements can include UV and IR energy and very small band pass increments of 1nm or less.

Light Measurement

Traceability, Calibration and Re-certification

Tristimulus Colorimeters and Spectroradiometers require annual calibration and re-certification.

Re-calibration is accomplished typically by returning the instrument to the manufacturer or a “Traceable” laboratory and having the instrument adjusted to known radiometric and colorimetric values of a “Traceable” light source.

A traceable lab returns their light source to an internationally recognized lab like NIST to maintain their traceable certification.

Once the instrument is re-calibrated it is certified with traceability to a recognized lab. (NIST Traceable).

Light Measurement

Light Measurement Recommendations

•Know what light source or combination of sources are really being used in a lighting environment.

•Be familiar with the requirements of National, International Standards and or Corporate Lighting Specifications that you should adhere to.

•Understand the differences and capabilities of Colorimeter / Tristimulus Instruments and Spectrally based instruments, Spectroradiometers.

•Be aware of the deficiencies in specifying based on Chromaticity Coordinates, CCT and CRI.

•Request the Spectral Power Distribution curves for your lighting system.

•When everything fails, buy a traceable instrument and Measure, Measure, Measure.

Thank You!

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