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Radiometry and Photometry Crib Sheet

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Radiant Energy	Q	joules	J
Radiant Flux (Power)	$\Phi = \frac{dQ}{dt}$	joules per second	J/s
	also known as	watts	W
Luminous Flux	Φ_v	lumens	lm
Maximum (photopic) spectral efficacy	$K_m = 683$ lumens per watt at 555 nm wavelength		
Maximum (scotopic) spectral efficacy	$K'_m = 1700$ lumens per watt at 507 nm wavelength		
Quantity of Light (luminous energy)	Q_v	lumen-seconds	lm-s
Solid Angle (spherical area/distance ²)	Ω	steradians	sr
Radiant Intensity	$I = \frac{d\Phi}{d\Omega}$	watts per steradian	W/sr
Luminous Intensity	$I_v = \frac{d\Phi_v}{d\Omega}$	lumens per steradian	lm/sr
	also known as	candelas	cd
Irradiance (incident on a detector)	$E = \frac{d\Phi}{dA_D}$	watts per square meter	W/m ²
Illuminance (incident on a detector)	$E_v = \frac{d\Phi_v}{dA_D}$	lumens per square meter	lm/m ²
	also known as	lux	lux
Radiant Exitance (from an emitter)	$M = \frac{d\Phi}{dA_S}$	watts per square meter	W/m ²
Luminous Exitance (from an emitter)	$M_v = \frac{d\Phi_v}{dA_S}$	lumens per square meter	lm/m ²
Radiance	$L = \frac{d^2\Phi}{d\Omega dA \cos \theta}$	watts per steradian	W/sr/m ²
		per square meter	
Luminance (brightness)	$L_v = \frac{d^2\Phi_v}{d\Omega dA \cos \theta}$	lumens per steradian	lm/sr/m ²
		per square meter	
		also known as	
also known as	nits	nt	

Chromaticity

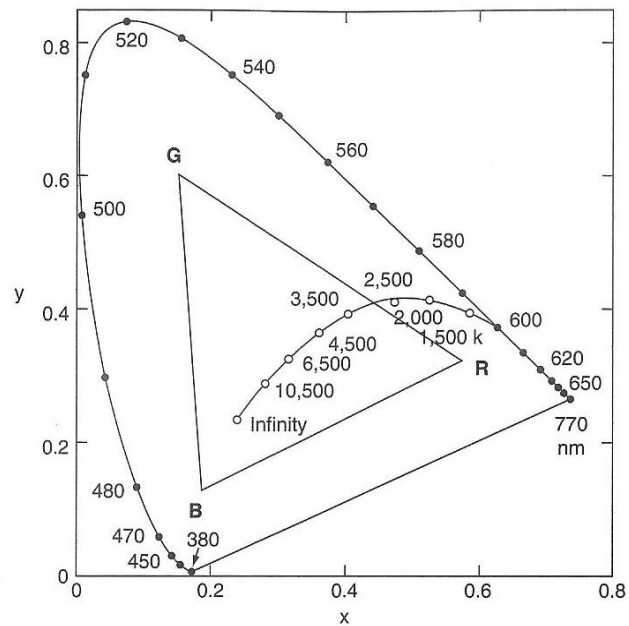
If X, Y, and Z are three tristimulus values, then chromaticity coordinates x, y, and z may be formed independent of brightness by normalizing by the sum of the tristimulus values:

$$x = \frac{X}{X+Y+Z} \quad y = \frac{Y}{X+Y+Z} \quad \text{and} \quad z = \frac{Z}{X+Y+Z} \quad \text{But since } z = 1-x-y$$

only two coordinates, x and y, can completely specify the chromaticity.

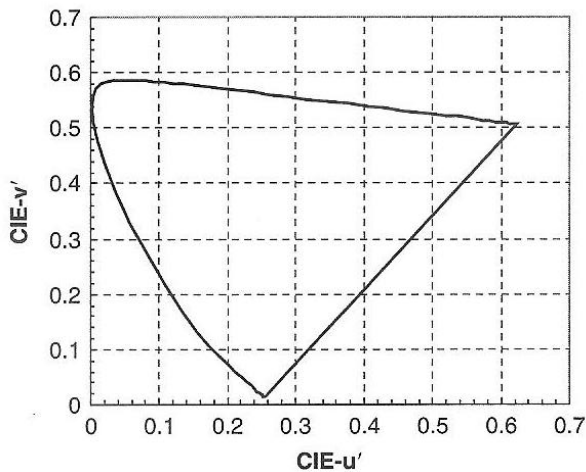
In 1931, CIE generated a curve in the x-y plane showing the pure monochromatic colors labeled wavelength. Blue is at the lower left end of an open horseshoe, tilted about 30 degrees counterclockwise, Green is at the top of the curve, and Red is at the bottom right end. White would be a little below the center of the space defined by the curve.

An additional curve showing the color of a black body at temperatures from 1000°K to infinity is drawn labeled by the temperature. This shows 6500°K at roughly where “white hot” would be. Interestingly, the color approaches blue for infinitely hot temperatures.



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Unfortunately, the x-y plane did not show uniformly how sensitive the human eye was to a “just noticeable difference.” CIE brought out a transformed version of the plane in 1976, the u'-v' plane:

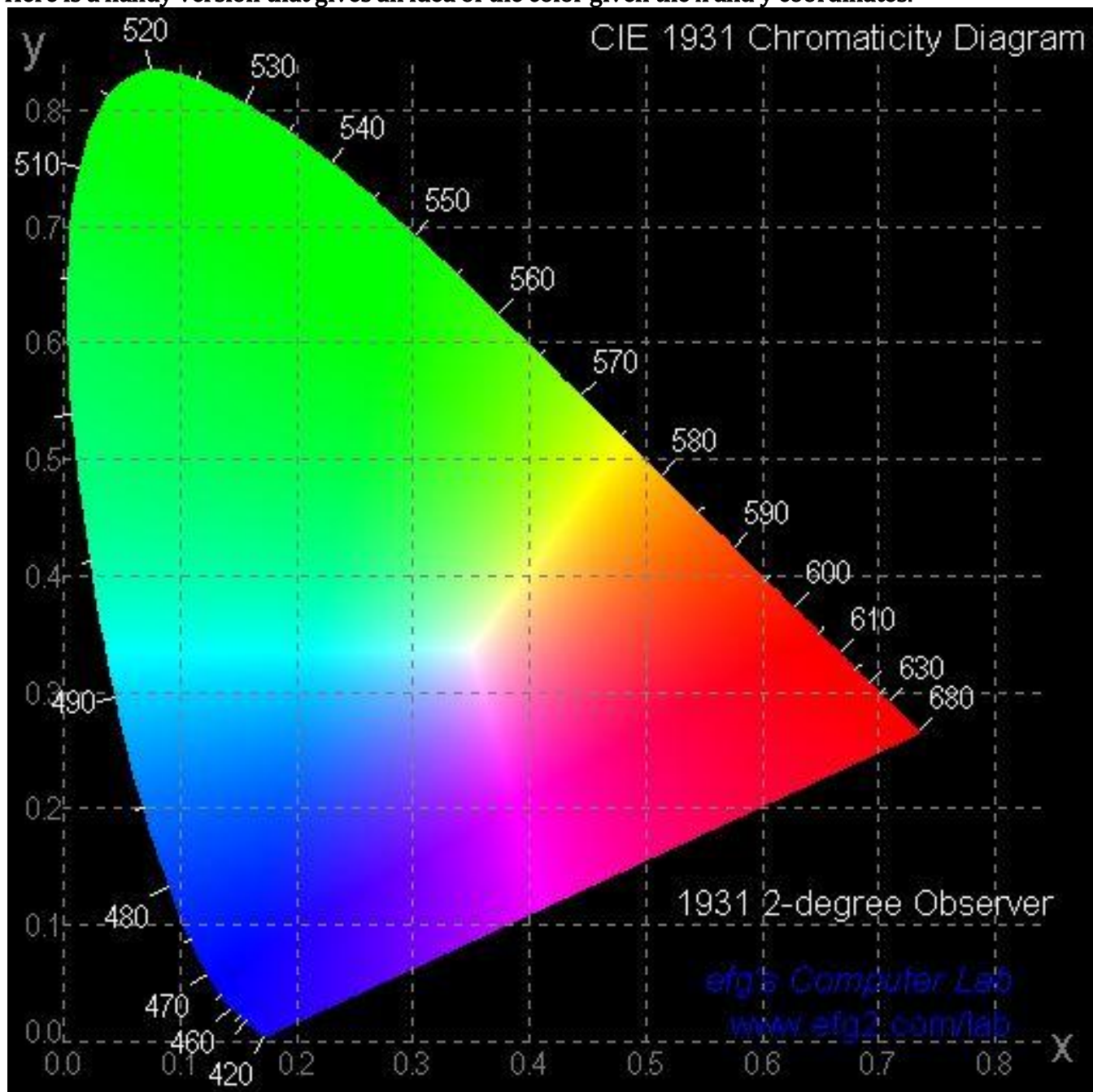


$$u' = \frac{4x}{12y-2x+3} \quad \text{and} \quad v' = \frac{9y}{12y-2x+3}$$

This has the effect of shortening and rotating the horseshoe more counterclockwise so that the right hand side is now almost horizontal. Now “just noticeable differences” are circles.

The color quality of a display can be shown by how well it can fill the entire curve. The color accuracy of a display can be shown by how far off the ideal various colors are located.

Here is a handy version that gives an idea of the color given the x and y coordinates.



The above is the most widely accepted chromaticity diagram, based on a narrow 2-degree field of vision. There is a more recent 1964 10-degree observer version. There are also the Dell, NTSC, EBU, SMPTE, short persistence, and long persistence versions. All these are slightly different and are optimized for particular applications.

For much more information, this is a marvelous website:

<http://www.efg2.com/Lab/Graphics/Colors/Chromaticity.htm>

Typical numbers:

100W incandescent light bulb gives off 82 watts of radiant flux which is 1740 lumens of luminous flux.

40W fluorescent lamp gives off 23.2 watts of radiant flux.

A typical He-Ne laser (like a pointer) is 5 milliwatts, which at 633 nm is 0.818 lumens.

Solar energy available outside the earth's atmosphere is 1357 watts per square meter.

Solar energy available at sea level is 600 to 900 watts per square meter.

Luminance of a black body at 6500°K is 3×10^9 candelas per square meter or 3 billion nits.

200 nits is a nice, bright display in a 4-inch size.

Non-SI units:

Luminous energy	talbot	1 lumen-second
Illuminance	meter candle (mc)	1 lumen per square meter = 1 lux
	footcandle (fc)	1 lumen per square foot
	nox	10^{-3} lumens per square meter = 10^{-3} lux
	phot (ph)	1 lumen per square centimeter
Luminous intensity	candlepower	1 candela (cd)
Luminance	nit (nt)	1 candela per square meter
	stilb (sb)	1 candela per square centimeter
	lambert (L)	$\frac{1}{\pi}$ candelas per square centimeter brightness of a perfectly diffusing surface that emits or reflects 1 lumen per square centimeter
	foot lambert (ft L)	$\frac{1}{\pi}$ candelas per square foot brightness of a perfectly diffusing surface that emits or reflects 1 lumen per square foot
	apostilb (asb)	$\frac{1}{\pi}$ candelas per square meter
	skot (sk)	10^{-3} apostilbs = $\frac{10^{-3}}{\pi}$ cd/m ²