**Color rendering index**

The **color rendering index** (**CRI**) (sometimes called *color rendition index*), is a quantitative measure of the ability of a [light source](http://en.wikipedia.org/wiki/Light_source) to reproduce the colors of various objects faithfully in comparison with an ideal or natural light source. Light sources with a high CRI are desirable in color-critical applications such as [photography](http://en.wikipedia.org/wiki/Photography) and [cinematography](http://en.wikipedia.org/wiki/Cinematography).[[1]](http://en.wikipedia.org/wiki/Color-rendering_index#cite_note-0) It is defined by the [International Commission on Illumination](http://en.wikipedia.org/wiki/International_Commission_on_Illumination) as follows:

**Color rendering**: Effect of an illuminant on the color appearance of objects by conscious or subconscious comparison with their color appearance under a reference illuminant [[2]](http://en.wikipedia.org/wiki/Color-rendering_index#cite_note-1)

Note that the CRI by itself does not indicate what the [color temperature](http://en.wikipedia.org/wiki/Color_temperature) of the reference light source is; therefore, it is customary to also cite the [correlated color temperature](http://en.wikipedia.org/wiki/Correlated_color_temperature) (CCT).

According to ([Schanda & Sándor 2005](http://en.wikipedia.org/wiki/Color-rendering_index" \l "CITEREFSchandaS.C3.A1ndor2005)), CRI is being deprecated in favor of measures based on [color appearance models](http://en.wikipedia.org/w/index.php?title=Color_appearance_model&action=edit&redlink=1), such as [CIECAM02](http://en.wikipedia.org/wiki/CIECAM02) and, for [daylight](http://en.wikipedia.org/wiki/Daylight) simulators, the CIE [Metamerism Index](http://en.wikipedia.org/w/index.php?title=Metamerism_Index&action=edit&redlink=1). ([Guo & Houser 2004](http://en.wikipedia.org/wiki/Color-rendering_index" \l "CITEREFGuoHouser2004)) and ([CIE 1995](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFCIE1995)) note that CRI is not a good indicator for use in visual assessment, especially for sources below 5000 K.

A newer version of the CRI has been developed (R96a), but it has not replaced the better-known Ra (general color rendering index).

|  |
| --- |
| **Contents**   * [1 History](http://en.wikipedia.org/wiki/Color-rendering_index#History) * [2 Test Method](http://en.wikipedia.org/wiki/Color-rendering_index#Test_Method)   + [2.1 Chromatic adaptation](http://en.wikipedia.org/wiki/Color-rendering_index#Chromatic_adaptation)   + [2.2 Test color samples](http://en.wikipedia.org/wiki/Color-rendering_index#Test_color_samples) * [3 R96a method](http://en.wikipedia.org/wiki/Color-rendering_index#R96a_method)   + [3.1 New test color samples](http://en.wikipedia.org/wiki/Color-rendering_index#New_test_color_samples) * [4 Example](http://en.wikipedia.org/wiki/Color-rendering_index#Example) * [5 Typical values](http://en.wikipedia.org/wiki/Color-rendering_index#Typical_values) * [6 Criticism and resolution](http://en.wikipedia.org/wiki/Color-rendering_index#Criticism_and_resolution) * [7 Footnotes](http://en.wikipedia.org/wiki/Color-rendering_index#Footnotes) * [8 References](http://en.wikipedia.org/wiki/Color-rendering_index#References) * [9 External links](http://en.wikipedia.org/wiki/Color-rendering_index#External_links) |

**History**

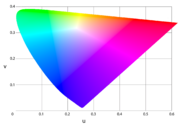
Around the middle of the 20th century, color scientists took an interest in assessing the ability of [artificial lights](http://en.wikipedia.org/wiki/Artificial_light) to accurately reproduce colors. European researchers attempted to describe illuminants by measuring the [spectral power distribution](http://en.wikipedia.org/wiki/Spectral_power_distribution) (SPD) in "representative" spectral bands, whereas their North American counterparts studied the [colorimetric](http://en.wikipedia.org/wiki/Colorimetric) effect of the illuminants on reference objects.[[3]](http://en.wikipedia.org/wiki/Color-rendering_index#cite_note-2)

The CIE assembled a committee to study the matter and accepted the proposal to use the latter approach, which has the virtue of not needing [spectrophotometry](http://en.wikipedia.org/wiki/Spectrophotometry), with a set of [Munsell](http://en.wikipedia.org/wiki/Munsell_color_system) samples. Eight samples of varying hue would be alternately lit with two illuminants, and the color appearance compared. Since no color appearance model existed at the time, it was decided to base the evaluation on color differences in a suitable color space, [CIEUVW](http://en.wikipedia.org/wiki/CIE_1964_color_space).

To deal with the problem of having to compare light sources of different correlated color temperatures (CCT), the CIE settled on using a reference [black body](http://en.wikipedia.org/wiki/Black_body) with the same color temperature for lamps with a CCT of under 5000 K, or a phase of CIE [standard illuminant](http://en.wikipedia.org/wiki/Standard_illuminant) D (daylight) otherwise. This presented a continuous range of color temperatures to choose a reference from. Any chromaticity difference between the source and reference illuminants were to be abridged with a von Kries-type [chromatic adaptation transform](http://en.wikipedia.org/wiki/Chromatic_adaptation_transform).

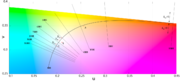
**Test Method**

The CRI is calculated by comparing the color rendering of the test source to that of a "perfect" source which is a black body radiator for sources with correlated color temperatures under 5000 K, and a phase of daylight otherwise (e.g. [D65](http://en.wikipedia.org/wiki/D65)). [Chromatic adaptation](http://en.wikipedia.org/wiki/Chromatic_adaptation) should be performed so that like quantities are compared. Specified in ([Nickerson & Jerome 1965](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFNickersonJerome1965)) and republished in ([CIE 1995](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFCIE1995)), the *Test Method* (also called *Test Sample Method* or *Test Color Method*) needs only [colorimetric](http://en.wikipedia.org/wiki/Colorimetric), rather than [spectrophotometric](http://en.wikipedia.org/wiki/Spectrophotometric), information.

[](http://en.wikipedia.org/wiki/File:CIE_1960_UCS.png)

[http://bits.wikimedia.org/skins-1.5/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:CIE_1960_UCS.png)

CIE 1960 UCS. Planckian locus and co-ordinates of several illuminants shown in illustration below.

[](http://en.wikipedia.org/wiki/File:Planckian-locus.png)

[http://bits.wikimedia.org/skins-1.5/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Planckian-locus.png)

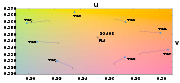
(u,v) chromaticity diagram with several CIE illuminants.

1. Using the [2° standard observer](http://en.wikipedia.org/wiki/CIE_1931_color_space#The_CIE_standard_observer), find the [chromaticity](http://en.wikipedia.org/wiki/Chromaticity) co-ordinates of the test source in the [CIE 1960 color space](http://en.wikipedia.org/wiki/CIE_1960_color_space).[[4]](http://en.wikipedia.org/wiki/Color-rendering_index#cite_note-3)
2. Determine the [correlated color temperature](http://en.wikipedia.org/wiki/Correlated_color_temperature) (CCT) of the test source by finding the closest point to the [Planckian locus](http://en.wikipedia.org/wiki/Planckian_locus) on the (u,v) chromaticity diagram.
3. If the test source has a CCT<5000 K, use a black body for reference, otherwise use CIE [standard illuminant](http://en.wikipedia.org/wiki/Standard_illuminant) D. Both sources should have the same CCT.
4. Ensure that the chromaticity distance (DC) of the test source to the Planckian locus is under 5.4E-3 in the CIE 1960 UCS. This ensures the meaningfulness of the result, as the CRI is only defined for light sources that are approximately white.[[5]](http://en.wikipedia.org/wiki/Color-rendering_index#cite_note-4) DC={\Delta}_{uv}=\sqrt{(u_r-u_t)^2+(v_r-v_t)^2}
5. Illuminate the first eight standard samples, from the fifteen listed below, alternately using both sources.
6. Using the 2° standard observer, find the chromaticity co-ordinates of the light reflected by each sample in the [CIE 1964 color space](http://en.wikipedia.org/wiki/CIE_1964_color_space).
7. Chromatically adapt each sample by a [von Kries transform](http://en.wikipedia.org/wiki/Von_Kries_transform).
8. For each sample, calculate the [Euclidean distance](http://en.wikipedia.org/wiki/Euclidean_distance) Δ*Ei* between the pair of co-ordinates.
9. Calculate the special (i.e., particular) CRI using the formula *Ri* = 100 − 4.6Δ*Ei*[[6]](http://en.wikipedia.org/wiki/Color-rendering_index#cite_note-5)[[7]](http://en.wikipedia.org/wiki/Color-rendering_index#cite_note-6)
10. Find the general CRI (Ra) by calculating the [arithmetic mean](http://en.wikipedia.org/wiki/Arithmetic_mean) of the special CRIs.

Note that the last three steps are equivalent to finding the mean [color difference](http://en.wikipedia.org/wiki/Color_difference), \Delta \bar{E}_{UVW}and using that to calculate *Ra*:

R_a=100-4.6 \Delta \bar{E}_{UVW}

**Chromatic adaptation**

[](http://en.wikipedia.org/wiki/File:CIE_CRI_TCS_under_FL4.svg)

[http://bits.wikimedia.org/skins-1.5/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:CIE_CRI_TCS_under_FL4.svg)

Chromatic adaptation of TCSs lit by CIE FL4 (short, black vectors, to indicate before and after) to a black body of 2940K (cyan circles).

([CIE 1995](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFCIE1995)) uses this von Kries chromatic transform equation to find the [corresponding color](http://en.wikipedia.org/w/index.php?title=Corresponding_color&action=edit&redlink=1) (uc,i,vc,i) for sample i:

u_{c,i}=\frac{10.872+0.404 (c_r/c_t) c_{t,i} - 4 (d_r/d_t) d_{t,i}}{16.518+1.481 (c_r/c_t) c_{t,i} - (d_r/d_t) d_{t,i}}

v_{c,i}=\frac{5.520}{16.518+1.481 (c_r/c_t) c_{t,i} - (d_r/d_t) d_{t,i}}

c=\left(4.0-u-10.0v \right)/v

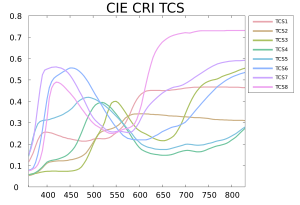
d=\left(1.708v-1.481u+0.404\right)/v

where subscripts r and t refer to reference and test light sources, respectively.

**Test color samples**

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Appr. Munsell** | **Appearance under daylight** | **Swatch** |
| TCS01 | 7,5 R 6/4 | Light greyish red |  |
| TCS02 | 5 Y 6/4 | Dark greyish yellow |  |
| TCS03 | 5 GY 6/8 | Strong yellow green |  |
| TCS04 | 2,5 G 6/6 | Moderate yellowish green |  |
| TCS05 | 10 BG 6/4 | Light bluish green |  |
| TCS06 | 5 PB 6/8 | Light blue |  |
| TCS07 | 2,5 P 6/8 | Light violet |  |
| TCS08 | 10 P 6/8 | Light reddish purple |  |
| TCS09 | 4,5 R 4/13 | Strong red |  |
| TCS10 | 5 Y 8/10 | Strong yellow |  |
| TCS11 | 4,5 G 5/8 | Strong green |  |
| TCS12 | 3 PB 3/11 | Strong blue |  |
| TCS13 | 5 YR 8/4 | Light yellowish pink ([skin](http://en.wikipedia.org/wiki/Human_skin_color)) |  |
| TCS14 | 5 GY 4/4 | Moderate olive green ([leaf](http://en.wikipedia.org/wiki/Leaf)) |  |
| TCS15 | 1 YR 6/4 | Asian skin |  |

As specified in ([CIE 1995](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFCIE1995)), the original test color samples (TCS) are taken from an early edition of the [Munsell](http://en.wikipedia.org/wiki/Munsell) Atlas. The first eight samples, a subset of the eighteen proposed in ([Nickerson 1960](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFNickerson1960)), are relatively low saturated colors and are evenly distributed over the complete range of hues.[[8]](http://en.wikipedia.org/wiki/Color-rendering_index#cite_note-7) These eight samples are employed to calculate the general color rendering index *Ra*. The last seven samples provide supplementary information about the color rendering properties of the light source; the first four for high saturation, and the last three as representatives of well-known objects. The reflectance spectra of these samples may be found in ([CIE 2004](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFCIE2004)),[[9]](http://en.wikipedia.org/wiki/Color-rendering_index" \l "cite_note-8) and their approximate Munsell notations are listed aside.[[10]](http://en.wikipedia.org/wiki/Color-rendering_index#cite_note-9)

[](http://en.wikipedia.org/wiki/File:CIE_CRI_TCS_SPDs.svg)

**R96a method**

In the CIE's 1991 Quadrennial Meeting, Technical Committee 1-33 (Color Rendering) was assembled to work on updating the color rendering method, as a result of which the R96a method was developed. The committee was dissolved in 1999, releasing ([CIE 1999](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFCIE1999)), but no firm recommendations, partly due to disagreements between researchers and manufacturers.[[11]](http://en.wikipedia.org/wiki/Color-rendering_index#cite_note-10)

[](http://en.wikipedia.org/wiki/File:CIE_CRI_TCS_chromaticities.svg)

The R96a method has a few distinguishing features:[[12]](http://en.wikipedia.org/wiki/Color-rendering_index" \l "cite_note-11)

* [A new set of test color samples](http://en.wikipedia.org/wiki/Color-rendering_index#New_test_color_samples)
* Six reference illuminants: D65, D50, black bodies of 4200K, 3450K, 2950K, and 2700K.
* A new chromatic adaptation transform: CIECAT94.
* Color difference evaluation in CIELAB.
* Adaptation of all colors to [D65](http://en.wikipedia.org/wiki/D65) (since CIELAB is well-tested under [D65](http://en.wikipedia.org/wiki/D65)).

It is conventional to use the original method; R96a should be explicitly mentioned if used.

**New test color samples**

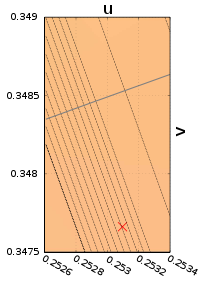
|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **TCS01\*** | **TCS02\*** | **TCS03\*** | **TCS04\*** | **TCS05\*** | **TCS06\*** | **TCS07\*** | **TCS08\*** | **TCS09\*** | **TCS10\*** |
| L\* | 40.9 | 61.1 | 81.6 | 72.0 | 55.7 | 51.7 | 30.0 | 51.0 | 68.7 | 63.9 |
| a\* | 51.0 | 28.8 | -4.2 | -29.4 | -43.4 | -26.4 | 23.2 | 47.3 | 14.2 | 11.7 |
| b\* | 26.3 | 57.9 | 80.3 | 58.9 | 35.6 | -24.6 | -49.6 | -13.8 | 17.4 | 17.3 |
|  |  |  |  |  |  |  |  |  |  |  |

As discussed in ([Schanda & Sándor 2005](http://en.wikipedia.org/wiki/Color-rendering_index" \l "CITEREFSchandaS.C3.A1ndor2005)), ([CIE 1999](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFCIE1999)) recommends the use of a Macbeth (now [X-Rite](http://en.wikipedia.org/wiki/X-Rite)) [color chart](http://en.wikipedia.org/wiki/Color_chart) owing to the obsolescence of the original samples, of which only [metameric](http://en.wikipedia.org/wiki/Metamerism_(color)) matches remain.[[13]](http://en.wikipedia.org/wiki/Color-rendering_index#cite_note-12) In addition to the eight ColorChart samples, two skin tone samples are defined (TCS09\* and TCS10\*). Accordingly, the updated general CRI is averaged over ten samples, not eight as before. Nevertheless, ([Hung 2002](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFHung2002)) has determined that the patches in ([CIE 1995](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFCIE1995)) give better correlations for any color difference than the Macbeth chart, whose samples are not equally distributed in a uniform color space.

**Example**

The CRI can also be theoretically derived from the SPD of the illuminant and samples since physical copies of the original color samples are difficult to find. In this method, care should be taken to use a sampling resolution fine enough to capture spikes in the SPD. The SPDs of the standard test colors are tabulated in 5nm increments ([CIE 2004](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFCIE2004)), so it is suggested to use interpolation up to the resolution of the illuminant's spectrophotometry.

Starting with the SPD, let us verify that the CRI of reference illuminant F4 is 51. The first step is to determine the [tristimulus values](http://en.wikipedia.org/wiki/Tristimulus_value) using the 1931 standard observer. Calculation of the [inner product](http://en.wikipedia.org/wiki/Inner_product) of the SPD with the standard observer's color matching functions (CMFs) yields (X,Y,Z)=(109.2,100.0,38.9) (after normalizing for Y=100). From this follow the xy chromaticity values:

[](http://en.wikipedia.org/wiki/File:CIE_1960_UCS,_FL4.svg)

[http://bits.wikimedia.org/skins-1.5/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:CIE_1960_UCS,_FL4.svg)

The tight isotherms are from 2935K–2945K. FL4 marked with a cross.

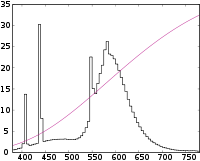
x=\frac{109.2}{109.2+100.0+38.9}=0.4402

y=\frac{100}{109.2+100.0+38.9}=0.4031

The next step is to convert these chromaticities to the [CIE 1960 UCS](http://en.wikipedia.org/wiki/CIE_1960_color_space) in order to be able to determine the CCT:

u=\frac{4 \times 0.4402}{-2 \times 0.4402 + 12 \times 0.4031 + 3}=0.2531

v=\frac{6 \times 0.4031}{-2 \times 0.4402 + 12 \times 0.4031 + 3}=0.3477

[](http://en.wikipedia.org/wiki/File:CIE_illuminant_F4_and_a_blackbody_of_2938K.svg)

[http://bits.wikimedia.org/skins-1.5/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:CIE_illuminant_F4_and_a_blackbody_of_2938K.svg)

Relative SPD of FL4 and a black body of equal CCT. Not normalized.

Examining the CIE 1960 UCS reveals this point to be closest to 2938 K on the Planckian locus, which has a co-ordinate of (0.2528, 0.3484). The distance of the test point to the locus is under the limit (5.4E-3), so we can continue the procedure, assured of a meaningful result:

\begin{align} DC&=\sqrt{ (0.2531-0.2528)^2+(0.3477-0.3484)^2 } \\
& =8.12 \times 10^{-4} < 5.4 \times 10^{-3} \end{align} 

We can verify the CCT by using [McCamy's approximation algorithm](http://en.wikipedia.org/wiki/Correlated_color_temperature#Approximation) to estimate the CCT from the xy chromaticities:

*CCTest*. = − 449*n*3 + 3525*n*2 − 6823.3*n* + 5520.33, where n=\frac{x-0.3320}{y-0.1858}.

Substituting (*x*,*y*) = (0.4402,0.4031) yields n=0.4979 and CCTest. = 2941 K, which is close enough. ([Robertson's method](http://en.wikipedia.org/wiki/Correlated_color_temperature#Robertson.27s_method) can be used for greater precision, but we will be content with 2940 K [sic] in order to replicate published results.) Since 2940 < 5000, we select a Planckian radiator of 2940 K as the reference illuminant.

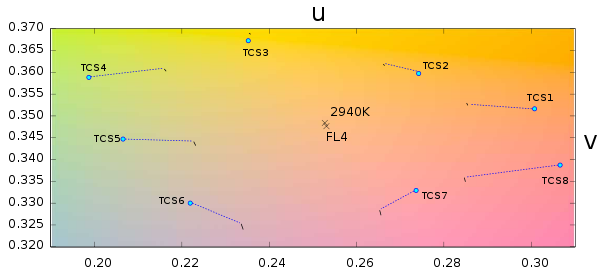
The next step is to determine the values of the test color samples under each illuminant in the [CIEUVW color space](http://en.wikipedia.org/wiki/CIE_1964_color_space). This is done by integrating the product of the CMF with the SPDs of the illuminant and the sample, then converting from CIEXYZ to CIEUVW:

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Illuminant** | | **TCS1** | **TCS2** | **TCS3** | **TCS4** | **TCS5** | **TCS6** | **TCS7** | **TCS8** |
| **Reference** | **U** | 39.22 | 17.06 | -13.94 | -40.83 | -35.55 | -23.37 | 16.43 | 44.64 |
| **V** | 2.65 | 9.00 | 14.97 | 7.88 | -2.86 | -13.94 | -12.17 | -8.01 |
| **W** | 62.84 | 61.08 | 61.10 | 58.11 | 59.16 | 58.29 | 60.47 | 63.77 |
| **CIE FL4** | **U** | 26.56 | 10.71 | -14.06 | -27.45 | -22.74 | -13.99 | 9.61 | 25.52 |
| **V** | 3.91 | 11.14 | 17.06 | 9.42 | -3.40 | -17.40 | -15.71 | 10.23 |
| **W** | 63.10 | 61.78 | 62.30 | 57.54 | 58.46 | 56.45 | 59.11 | 61.69 |
| **CIE FL4 (CAT)** | **U** | 26.34 | 10.45 | -14.36 | -27.78 | -23.10 | -14.33 | 9.37 | 25.33 |
| **V** | 4.34 | 11.42 | 17.26 | 9.81 | -2.70 | -16.44 | -14.82 | -9.47 |
| **W** | 63.10 | 61.78 | 62.30 | 57.54 | 58.46 | 56.45 | 59.11 | 61.69 |

From this we can calculate the color difference between the chromatically adapted samples (labeled "CAT") and those illuminated by the reference. (The Euclidean metric is used to calculate the color difference in CIEUVW.) The special CRI is simply *Ri* = 100 − 4.6Δ*EUVW*.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **TCS1** | **TCS2** | **TCS3** | **TCS4** | **TCS5** | **TCS6** | **TCS7** | **TCS8** |
| **Δ*EUVW*** | 12.99 | 7.07 | 2.63 | 13.20 | 12.47 | 9.56 | 7.66 | 19.48 |
| **Ri** | 40.2 | 67.5 | 87.9 | 39.3 | 42.6 | 56.0 | 64.8 | 10.4 |

Finally, the general color rendering index is mean of the special CRI's: 51.

[](http://en.wikipedia.org/wiki/File:CIE_CRI_TCS_under_FL4.svg)

[http://bits.wikimedia.org/skins-1.5/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:CIE_CRI_TCS_under_FL4.svg)

The cyan circles indicate the TCS under the *reference* illuminant. The short, black, vectors indicate the TCS under the *test* illuminant, before and after chromatic adaptation transformation (CAT). (The vectors are short because the white points are close.) The post-CAT end of the vector lies NW, mirroring the chromaticity vector between the reference and test illuminants.  
The special CRIs are reflected in the length of the dotted lines linking the chromaticities of the samples under the reference and chromatically adapted test illuminants, respectively. Short distances, as in the case of TCS3, result in a high special CRI (87.9), whereas long distances, as in the case of TCS8, result in a low special CRI (10.4). In simpler terms, TCS3 reproduces better under FL4 than does TCS8 (relative to a black body).

**[**[**edit**](http://en.wikipedia.org/w/index.php?title=Color_rendering_index&action=edit&section=8)**] Typical values**

|  |  |  |
| --- | --- | --- |
| **Light source** | **CCT (K)** | **CRI** |
| Low Pressure Sodium (LPS/SOX) | 1800 | ~5 |
| Clear Mercury-vapor | 6410 | 17 |
| High Pressure Sodium (HPS/SON) | 2100 | 24 |
| Coated Mercury-vapor | 3600 | 49 |
| **Halophosphate Warm White Fluorescent** | **2940** | **51** |
| Halophosphate Cool White fluorescent | 4230 | 64 |
| Tri-phosphor Warm White Fluorescent | 2940 | 73 |
| Halophosphate Cool Daylight Fluorescent | 6430 | 76 |
| "White" SON | 2700 | 82 |
| Quartz Metal Halide | 4200 | 85 |
| Tri-phosphor Cool White fluorescent | 4080 | 89 |
| Ceramic Metal Halide | 5400 | 96 |
| Incandescent/Halogen Light Bulb | 3200 | 100 |

A reference source, such as black body radiation, is defined as having a CRI of 100. This is why [incandescent lamps](http://en.wikipedia.org/wiki/Incandescent_lamp) have that rating, as they are, in effect, almost black body radiators. The best possible faithfulness to a reference is specified by a CRI of one hundred, while the very poorest is specified by a CRI of zero. A high CRI by itself does not imply a good rendition of color, because the reference itself may have an imbalanced SPD if it has an extreme color temperature (see [next section](http://en.wikipedia.org/wiki/Color-rendering_index#Criticism_and_resolution)).

**Criticism and resolution**

([Ohno 2006](http://en.wikipedia.org/wiki/Color-rendering_index" \l "CITEREFOhno2006)) and others have criticised CRI for not always correlating well with subjective color rendering quality in practice, particularly for light sources with spiky emission spectra such as fluorescent lamps or white [LEDs](http://en.wikipedia.org/wiki/Light-emitting_diode). Another problem is that the CRI is discontinuous at 5000 K,[[14]](http://en.wikipedia.org/wiki/Color-rendering_index" \l "cite_note-13) because the chromaticity of the reference moves from the [Planckian locus](http://en.wikipedia.org/wiki/Planckian_locus) to the [CIE Daylight Locus](http://en.wikipedia.org/w/index.php?title=CIE_Daylight_Locus&action=edit&redlink=1). ([Davis & Ohno 2006](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFDavisOhno2006)) identify several other issues, which they address in their [Color Quality Scale](http://en.wikipedia.org/wiki/Color_Quality_Scale) (CQS):

* The color space in which the color distance is calculated (CIEUVW) is obsolete and nonuniform. Use [CIELAB](http://en.wikipedia.org/wiki/CIELAB) or [CIELUV](http://en.wikipedia.org/wiki/CIELUV) instead.
* The chromatic adaptation transform used ([Von Kries transform](http://en.wikipedia.org/wiki/Von_Kries_transform)) is inadequate. Use [CMCCAT2000](http://en.wikipedia.org/w/index.php?title=CMCCAT2000&action=edit&redlink=1) or [CIECAT02](http://en.wikipedia.org/wiki/CIECAM02) instead.
* Calculating the arithmetic mean of the errors diminishes the contribution of any single large deviation. Two light sources with similar CRI may perform significantly differently if one has a particularly low special CRI in a spectral band that is important for the application. Use the [root mean square deviation](http://en.wikipedia.org/wiki/Root_mean_square_deviation) instead.
* The metric is not perceptual; all errors are equally weighted, whereas humans favor certain errors over others. A color can be more saturated or less saturated without a change in the numerical value of ∆Ei, while in general a saturated color is experienced as being more attractive.
* A negative CRI is difficult to interpret. Normalize the scale from 0 to 100 using the formula R_{out}=10 \ln \left[\exp(R_{in}/10)+1\right]
* The CRI can not be calculated for light sources that do not have a CCT (non-white light).
* Eight samples are not enough since manufacturers can optimize the emission spectra of their lamps to reproduce them faithfully, but otherwise perform poorly. Use more samples (they suggest fifteen for CQS).
* The samples are not saturated enough to pose difficulty for reproduction.
* CRI merely measures the faithfulness of any illuminant to an ideal source with the same CCT, but the ideal source itself may not render colors well if it has an extreme color temperature, due to a lack of energy at either short or long wavelengths (i.e., it may be excessively blue or red). Weight the result by the ratio of the [gamut](http://en.wikipedia.org/wiki/Gamut) area of the polygon formed by the fifteen samples in CIELAB for 6500 K to the gamut area for the test source. 6500 K is chosen for reference since it has a relatively even distribution of energy over the visible spectrum and hence high gamut area. This normalizes the multiplication factor.

([CIE 2007](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFCIE2007)) "reviews the applicability of the CIE colour rendering index to white LED light sources based on the results of visual experiments." Chaired by Davis, CIE TC 1-69(C) is currently investigating "new methods for assessing the colour rendition properties of white-light sources used for illumination, including solid-state light sources, with the goal of recommending new assessment procedures ... by March, 2010."[[15]](http://en.wikipedia.org/wiki/Color-rendering_index#cite_note-14)

For a comprehensive review of alternative color rendering indices see ([Guo & Houser 2004](http://en.wikipedia.org/wiki/Color-rendering_index" \l "CITEREFGuoHouser2004)).

**Footnotes**

1. [**^**](http://en.wikipedia.org/wiki/Color-rendering_index#cite_ref-0) ["Compare these images of a color chart taken under one light source with CRI 70 and another with CRI 85"](http://www.lightingdesignlab.com/articles/cri/cribig.htm). Lightingdesignlab.com. <http://www.lightingdesignlab.com/articles/cri/cribig.htm>. Retrieved 2009-04-16.
2. [**^**](http://en.wikipedia.org/wiki/Color-rendering_index#cite_ref-1) CIE 17.4|[International Lighting Vocabulary](http://www.cie.co.at/publ/abst/17-4-89.html), ([Schanda 2002](http://en.wikipedia.org/wiki/Color-rendering_index" \l "CITEREFSchanda2002))
3. [**^**](http://en.wikipedia.org/wiki/Color-rendering_index#cite_ref-2) American approach is expounded in ([Nickerson 1960](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFNickerson1960)), and the European approach in ([Barnes 1957](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFBarnes1957)), and ([Crawford 1959](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFCrawford1959)). See ([Schanda & Sándor 2003](http://en.wikipedia.org/wiki/Color-rendering_index" \l "CITEREFSchandaS.C3.A1ndor2003)) for a historical overview.
4. [**^**](http://en.wikipedia.org/wiki/Color-rendering_index#cite_ref-3) Note that when CRI was designed in 1965, the most perceptually uniform chromaticity space was the [CIE 1960 UCS](http://en.wikipedia.org/wiki/CIE_1960_color_space), the [CIE 1976 UCS](http://en.wikipedia.org/wiki/CIELUV_color_space) not yet having been invented.
5. [**^**](http://en.wikipedia.org/wiki/Color-rendering_index#cite_ref-4) ([CIE 1995](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFCIE1995)), [Section 5.3: Tolerance for reference illuminant](http://resodance.com/ali/CRI_prob.html)
6. [**^**](http://en.wikipedia.org/wiki/Color-rendering_index#cite_ref-5) Per ([Schanda & Sándor 2003](http://en.wikipedia.org/wiki/Color-rendering_index" \l "CITEREFSchandaS.C3.A1ndor2003)), ([Schanda 2002](http://en.wikipedia.org/wiki/Color-rendering_index" \l "CITEREFSchanda2002)) and, as demonstrated in the [Example](http://en.wikipedia.org/wiki/Color-rendering_index#Example) section, the coefficient was chosen as 4.6 so that the CRI of the CIE [standard illuminant](http://en.wikipedia.org/wiki/Standard_illuminant) F4, an obsolete "warm white" calcium halophosphate [fluorescent lamp](http://en.wikipedia.org/wiki/Fluorescent_lamp) would be 51. Today's fluorescent "[full-spectrum lights](http://en.wikipedia.org/wiki/Full-spectrum_light)" boast CRIs approaching 100; e.g, [Philips TL950](http://www.truesun.com/philips_TL950.php) or [EP patent 1184893](http://v3.espacenet.com/textdoc?DB=EPODOC&IDX=EP1184893) . ([Thornton 1972](http://en.wikipedia.org/wiki/Color-rendering_index#CITEREFThornton1972)) compares older products; ([Guo & Houser 2004](http://en.wikipedia.org/wiki/Color-rendering_index" \l "CITEREFGuoHouser2004)) compares newer ones.
7. [**^**](http://en.wikipedia.org/wiki/Color-rendering_index#cite_ref-6) It appeared that *Ri* could be negative (Δ*Ei* ≥ 22), and this was indeed calculated for some lamp test colors, especially TCS9 (strong red).
8. [**^**](http://en.wikipedia.org/wiki/Color-rendering_index#cite_ref-7) See the CIE 1960 UCS diagram towards the end of the [Example](http://en.wikipedia.org/wiki/Color-rendering_index#Example) section.
9. [**^**](http://en.wikipedia.org/wiki/Color-rendering_index#cite_ref-8) [TCS spectra in CSV form](http://photometry.kriss.re.kr/wiki/img_auth.php/4/47/CIE_TCS.csv), Korea Research Institute of Standards and Science.
10. [**^**](http://en.wikipedia.org/wiki/Color-rendering_index#cite_ref-9) [Munsell Renotation Data](http://www.cis.rit.edu/mcsl/online/munsell.php), *Munsell Color Science Laboratory*, [Rochester Institute of Technology](http://en.wikipedia.org/wiki/Rochester_Institute_of_Technology)
11. [**^**](http://en.wikipedia.org/wiki/Color-rendering_index#cite_ref-10) "Authors’ response to SA Fotios and JA Lynes" in ([Schanda & Sándor 2005](http://en.wikipedia.org/wiki/Color-rendering_index" \l "CITEREFSchandaS.C3.A1ndor2005)): *The main message of our investigations is an answer to the lamp industry, who still use the colour rendering index and the lamp efficacy as parameters for optimizing their lamp spectra, and have turned down the work of CIE TC 1-33 by stating that there are not enough visual experiments showing the shortcomings of the CIE colour rendering calculation method.*
12. [**^**](http://en.wikipedia.org/wiki/Color-rendering_index#cite_ref-11) See "Past research to improve the CRI" in ([Bodrogi 2004](http://en.wikipedia.org/wiki/Color-rendering_index" \l "CITEREFBodrogi2004))
13. [**^**](http://en.wikipedia.org/wiki/Color-rendering_index#cite_ref-12) [X-Rite ColorChecker Chart](http://www.xrite.com/product_overview.aspx?ID=820&Action=Library).
14. [**^**](http://en.wikipedia.org/wiki/Color-rendering_index#cite_ref-13) "Authors’ response to SA Fotios and JA Lynes" in ([Schanda & Sándor 2005](http://en.wikipedia.org/wiki/Color-rendering_index" \l "CITEREFSchandaS.C3.A1ndor2005)): *It is quite obvious that just at 5000 K, where the reference illuminant has to be changed, the present system shows discontinuity.'*
15. [**^**](http://en.wikipedia.org/wiki/Color-rendering_index#cite_ref-14) [CIE Activity Report. Division 1: Vision and Color](http://www.cie.co.at/div1/ActReps/D1ActivityReport08.pdf), pg.21, January 2008.

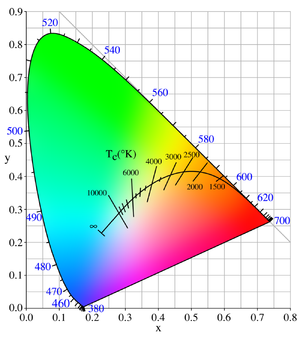
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  + Schanda, János; Sándor, Norbert (2005), ["Visual colour-rendering experiments"](http://www.knt.vein.hu/staff/schandaj/SJCV-Publ-2005/521.pdf), *AIC Colour '05: 10th Congress of the International Colour Association*, pp. 511–514, <http://www.knt.vein.hu/staff/schandaj/SJCV-Publ-2005/521.pdf>
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**External links**

* [MATLAB script for calculating measures of light source color](http://www.lrc.rpi.edu/programs/nlpip/lightinganswers/lightsources/appendixb1.asp), [Rensselaer Polytechnic Institute](http://en.wikipedia.org/wiki/Rensselaer_Polytechnic_Institute), 2004.
* [Excel spreadsheet with a cornucopia of data](http://www.lightinglab.fi/teaching/217/CRI_calculation.xls), Lighting Laboratory of the [Helsinki University of Technology](http://en.wikipedia.org/wiki/Helsinki_University_of_Technology)
* [Philips Fluorescent Light Source Color Charts](http://www.lsiadapt.com/media/2353/Fluorescent%20Light%20Source%20Color%20Charts.pdf) (reproduced with permission from [Fluorescent Cross Reference Guide](http://www.nam.lighting.philips.com/us/ecatalog/catalogs/2006_SAG100_Specialty.pdf), pg. 136.)
* [Uncertainty evaluation for measurement of LED colour, Metrologia](http://stacks.iop.org/0026-1394/46/704)

**Planckian locus**

[](http://en.wikipedia.org/wiki/File:PlanckianLocus.png)

[http://bits.wikimedia.org/skins-1.5/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:PlanckianLocus.png)

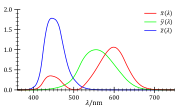
Planckian locus in the CIE 1931 chromaticity diagram

In [physics](http://en.wikipedia.org/wiki/Physics) and [color science](http://en.wikipedia.org/wiki/Color_science), the **Planckian locus** is the path or [*locus*](http://en.wikipedia.org/wiki/Locus_(mathematics)) that the color of an [incandescent](http://en.wikipedia.org/wiki/Incandescent) [black body](http://en.wikipedia.org/wiki/Black_body) would take in a particular [chromaticity space](http://en.wikipedia.org/wiki/Chromaticity_space) as the blackbody [temperature](http://en.wikipedia.org/wiki/Temperature) changes. It goes from deep [red](http://en.wikipedia.org/wiki/Red) at low temperatures through [orange](http://en.wikipedia.org/wiki/Orange_(color)), [yellowish](http://en.wikipedia.org/wiki/Yellow) white, [white](http://en.wikipedia.org/wiki/White), and finally [bluish](http://en.wikipedia.org/wiki/Blue) white at very high temperatures.

A [color space](http://en.wikipedia.org/wiki/Color_space) is a [three-dimensional space](http://en.wikipedia.org/wiki/Three-dimensional_space); that is, a color is specified by a set of three numbers (for example, either the [CIE](http://en.wikipedia.org/wiki/CIE_1931_color_space) coordinates *X*, *Y*, and *Z*, or other values such as [hue](http://en.wikipedia.org/wiki/Hue), [colorfulness](http://en.wikipedia.org/wiki/Colorfulness), and [luminance](http://en.wikipedia.org/wiki/Luminance)) which specify the color and brightness of a particular homogeneous visual stimulus. A chromaticity is a color projected into a [two-dimensional space](http://en.wikipedia.org/wiki/Two-dimensional_space) that ignores brightness. For example, the standard [CIE XYZ color space](http://en.wikipedia.org/wiki/CIE_XYZ_color_space) projects directly to the corresponding chromaticity space specified by the two chromaticity coordinates known as *x* and *y*, making the familiar chromaticity diagram shown in the figure. The Planckian locus, the path that the color of a black body takes as the blackbody temperature changes, is often shown in this standard chromaticity space.

|  |
| --- |
| **Contents**   * [1 The Planckian locus in the XYZ color space](http://en.wikipedia.org/wiki/Planckian_locus#The_Planckian_locus_in_the_XYZ_color_space)   + [1.1 Approximation](http://en.wikipedia.org/wiki/Planckian_locus#Approximation) * [2 Correlated color temperature](http://en.wikipedia.org/wiki/Planckian_locus#Correlated_color_temperature)   + [2.1 International Temperature Scale](http://en.wikipedia.org/wiki/Planckian_locus#International_Temperature_Scale) * [3 References](http://en.wikipedia.org/wiki/Planckian_locus#References) * [4 External links](http://en.wikipedia.org/wiki/Planckian_locus#External_links) |

**The Planckian locus in the XYZ color space**

[](http://en.wikipedia.org/wiki/File:CIE_1931_XYZ_Color_Matching_Functions.svg)

[http://bits.wikimedia.org/skins-1.5/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:CIE_1931_XYZ_Color_Matching_Functions.svg)

[CIE 1931 Standard Colorimetric Observer](http://www.cie.co.at/main/freepubs.html) functions used to map blackbody spectra to XYZ coordinates

In the [CIE XYZ color space](http://en.wikipedia.org/wiki/CIE_1931_color_space), the three coordinates defining a color are given by *X*, *Y*, and *Z*:[[1]](http://en.wikipedia.org/wiki/Planckian_locus" \l "cite_note-stiles-0)

X_T = \int_0^\infty X(\lambda)I(\lambda,T)\,d\lambda

Y_T = \int_0^\infty Y(\lambda)I(\lambda,T)\,d\lambda

Z_T = \int_0^\infty Z(\lambda)I(\lambda,T)\,d\lambda

where *I*(λ,T) is the spectral [radiance](http://en.wikipedia.org/wiki/Radiance) of the light being viewed, and *X*(*λ*), *Y*(*λ*) and *Z*(*λ*) are the [color matching functions](http://en.wikipedia.org/wiki/Color_matching_function) of the CIE [standard colorimetric observer](http://en.wikipedia.org/wiki/Standard_colorimetric_observer), shown in the diagram on the right, and *λ* is the wavelength. The Planckian locus is determined by substituting into the above equations the black body spectral radiance, which is given by [Planck's law](http://en.wikipedia.org/wiki/Planck%27s_law):

I(\lambda,T) =\frac{2\pi hc^2}{\lambda^5}\frac{1}{\exp\left(\frac{hc/\lambda}{kT}\right)-1}

where:

*I* is the black body spectral radiance (power per unit area per unit solid angle per unit wavelength)

*T* is the [temperature](http://en.wikipedia.org/wiki/Temperature) of the black body

*h* is [Planck's constant](http://en.wikipedia.org/wiki/Planck%27s_constant)

*c* is the [speed of light](http://en.wikipedia.org/wiki/Speed_of_light)

*k* is [Boltzmann's constant](http://en.wikipedia.org/wiki/Boltzmann%27s_constant)

This will give the Planckian locus in CIE XYZ color space. If these coordinates are *XT*, *YT*, *ZT* where *T* is the temperature, then in the CIE chromaticity coordinates will be

x_T = \frac{X_T}{X_T+Y_T+Z_T}

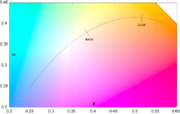
y_T = \frac{Y_T}{X_T+Y_T+Z_T}

**Approximation**

The Planckian locus in *xy* space is depicted as a curve in the chromaticity diagram above. While it is possible to compute the CIE *xy* co-ordinates exactly given the above formulas, it is faster to use approximations. Since the [mired](http://en.wikipedia.org/wiki/Mired) scale changes more evenly along the locus than the temperature itself, it is common for such approximations to be functions of the reciprocal temperature. Kim *et al.* uses a cubic spline:[[2]](http://en.wikipedia.org/wiki/Planckian_locus" \l "cite_note-1)[[3]](http://en.wikipedia.org/wiki/Planckian_locus#cite_note-2)

x_c=\begin{cases}
-0.2661239 \frac{10^9}{T^3} - 0.2343580 \frac{10^6}{T^2} + 0.8776956 \frac{10^3}{T} + 0.179910 & 1667\text{K} \leq T \leq 4000\text{K} \\
-3.0258469 \frac{10^9}{T^3}+2.1070379 \frac{10^6}{T^2} + 0.2226347 \frac{10^3}{T} + 0.24039 & 4000\text{K} \leq T \leq 25000\text{K}
\end{cases}

y_c=\begin{cases}
-1.1063814 x_c^3 - 1.34811020 x_c^2 + 2.18555832 x_c - 0.20219683 & 1667\text{K} \leq T \leq 2222\text{K} \\
-0.9549476 x_c^3 - 1.37418593 x_c^2 + 2.09137015 x_c - 0.16748867 & 2222\text{K} \leq T \leq 4000\text{K} \\
+3.0817580 x_c^3 - 5.87338670 x_c^2 + 3.75112997 x_c - 0.37001483 & 4000\text{K} \leq T \leq 25000\text{K}
\end{cases}

[](http://en.wikipedia.org/wiki/File:Planckian-locus-approximation.png)

[http://bits.wikimedia.org/skins-1.5/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Planckian-locus-approximation.png)

Kim *et al.'*s approximation to the Planckian locus (shown in red). The notches demarcate the three splines (shown in blue).

The Planckian locus can also be approximated in the CIE 1960 UCS, which is used to compute CCT and CRI, using the following expressions:[[4]](http://en.wikipedia.org/wiki/Planckian_locus" \l "cite_note-3)

\bar{u}(T)=\frac{0.860117757+1.54118254 \times 10^{-4}T + 1.28641212 \times 10^{-7} T^2}{1+8.42420235 \times 10^{-4}T + 7.08145163 \times 10^{-7}T^2}

\bar{v}(T)=\frac{0.317398726+4.22806245 \times 10^{-5}T + 4.20481691 \times 10^{-8} T^2}{1-2.89741816 \times 10^{-5}T+1.61456053 \times 10^{-7}T^2}

This approximation is accurate to within \left| u-\bar{u} \right| < 8\times10^{-5}and \left|v-\bar{v}\right|<9\times10^{-5}for 1000*K* < *T* < 15,000*K*

**Correlated color temperature**

The **correlated color temperature** (Tcp) is the temperature

of the Planckian radiator whose perceived colour most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions

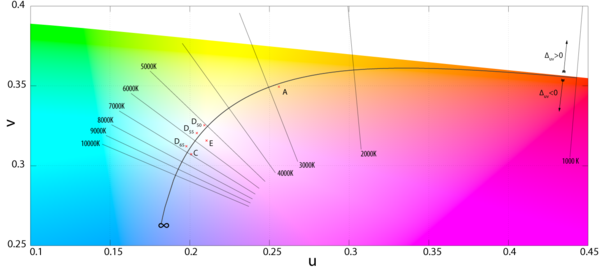
— [CIE/IEC 17.4:1987](http://www.cie.co.at/publ/abst/17-4-89.html) , International Lighting Vocabulary ([ISBN 3900734070](http://en.wikipedia.org/wiki/Special:BookSources/3900734070))[[5]](http://en.wikipedia.org/wiki/Planckian_locus" \l "cite_note-4)

The mathematical procedure for determining the [correlated color temperature](http://en.wikipedia.org/wiki/Correlated_color_temperature) involves finding the closest point to the light source's [white point](http://en.wikipedia.org/wiki/White_point) on the Planckian locus. Since the CIE's 1959 meeting in Brussels, the Planckian locus has been computed using the [CIE 1960 color space](http://en.wikipedia.org/wiki/CIE_1960_color_space), also known as MacAdam's (u,v) diagram.[[6]](http://en.wikipedia.org/wiki/Planckian_locus#cite_note-5) Today, the CIE 1960 color space is deprecated for other purposes:[[7]](http://en.wikipedia.org/wiki/Planckian_locus" \l "cite_note-6)

The 1960 UCS diagram and 1964 Uniform Space are declared obsolete recommendation in CIE 15.2 (1986), but have been retained for the time being for calculating colour rendering indices and correlated colour temperature.

—CIE 13.3 (1995) , [Method of Measuring and Specifying Colour Rendering Properties of Light Sources](http://www.cie.co.at/publ/abst/13-3-95.html)

Owing to the perceptual inaccuracy inherent to the concept, it suffices to calculate to within 2K at lower CCTs and 10K at higher CCTs to reach the threshold of imperceptibility.[[8]](http://en.wikipedia.org/wiki/Planckian_locus#cite_note-7)

[](http://en.wikipedia.org/wiki/File:Planckian-locus.png)

[http://bits.wikimedia.org/skins-1.5/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Planckian-locus.png)

Close up of the [CIE 1960 UCS](http://en.wikipedia.org/wiki/CIE_1960_color_space). The isotherms are perpendicular to the Planckian locus, and are drawn to indicate the maximum distance from the locus that the CIE considers the correlated color temperature to the meaningful: \Delta_{uv}=\pm 0.05

**International Temperature Scale**

The Planckian locus is derived by the determining the chromaticity values of a Planckian radiator using the standard colorimetric observer. The relative SPD of Planckian radiator follows Planck's law, and depends on the second radiation constant, *c*2 = *hc* / *k*. As measuring techniques have improved, the [General Conference on Weights and Measures](http://en.wikipedia.org/wiki/General_Conference_on_Weights_and_Measures) has revised its estimate of this constant, with the [International Temperature Scale](http://en.wikipedia.org/wiki/International_Temperature_Scale) (and briefly, the *International Practical Temperature Scale*). These successive revisions caused a shift in the Planckian locus and, as a result, the correlated color temperature scale. Before ceasing publication of [standard illuminants](http://en.wikipedia.org/wiki/Standard_illuminant), the CIE worked around this problem by explicitly specifying the form of the SPD, rather than making references to black bodies and a color temperature. Nevertheless, it is useful to be aware of previous revisions in order to be able to verify calculations made in older texts:[[9]](http://en.wikipedia.org/wiki/Planckian_locus" \l "cite_note-8)[[10]](http://en.wikipedia.org/wiki/Planckian_locus#cite_note-9)

* c_2=1.432 \times 10^{-2} \text{m·K}(ITS-27). Note: Was in effect during the standardization of Illuminants A, B, C (1931), however the CIE used the value recommended by the U.S. [National Bureau of Standards](http://en.wikipedia.org/wiki/National_Bureau_of_Standards), 1.435 × 10-2[[11]](http://en.wikipedia.org/wiki/Planckian_locus#cite_note-10)[[12]](http://en.wikipedia.org/wiki/Planckian_locus#cite_note-11)
* c_2=1.4380 \times 10^{-2} \text{m·K}(IPTS-48). In effect for Illuminant series D (formalized in 1967).
* c_2=1.4388 \times 10^{-2} \text{m·K}(ITS-68), (ITS-90). Often used in recent papers.
* c_2=1.4387752(25) \times 10^{-2} \text{m·K}([CODATA](http://en.wikipedia.org/wiki/CODATA), 2006). Current value, as of 2008.[[13]](http://en.wikipedia.org/wiki/Planckian_locus#cite_note-12)

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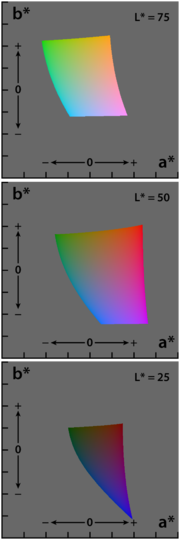
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**External links**

* [Numerical table of color temperature and the corresponding xy and sRGB coordinates for both the 1931 and 1964 CMFs](http://www.vendian.org/mncharity/dir3/blackbody/UnstableURLs/bbr_color.html), by Mitchell Charity.
* [Planckian xy locus for 1000K-25000K using the 2° CMF, in 1K increments](http://www.aim-dtp.net/aim/technology/cie_xyz/k2xy.txt), by Timo Autiokari.

# Lab color space

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[](http://en.wikipedia.org/wiki/File:Lab_color_space.png)

[http://bits.wikimedia.org/skins-1.5/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Lab_color_space.png)

The CIE 1976 (*L*\*, *a*\*, *b*\*) color space (CIELAB), showing only colors that fit within the [sRGB](http://en.wikipedia.org/wiki/SRGB_color_space) gamut (and can therefore be displayed on a typical computer display). Each axis of each square ranges from -128 to 128.

A ***Lab* color space** is a [color-opponent](http://en.wikipedia.org/wiki/Opponent_process) space with dimension ***L*** for [lightness](http://en.wikipedia.org/wiki/Lightness_(color)) and ***a*** and ***b*** for the color-opponent dimensions, based on nonlinearly-compressed [CIE XYZ color space](http://en.wikipedia.org/wiki/CIE_XYZ_color_space) coordinates.

The coordinates of the **Hunter 1948 *L*, *a*, *b* color space** are *L*, *a*, and *b*.[[1]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-Hunter1948a-0)[[2]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-Hunter1948b-1) However, *Lab* is now more often used as an informal abbreviation for the **CIE 1976 (*L\**, *a\**, *b\**) color space** (also called CIELAB, whose coordinates are actually *L\**, *a\**, and *b\**). Thus the initials *Lab* by themselves are somewhat ambiguous. The color spaces are related in purpose, but differ in implementation.

Both spaces are derived from the "master" space [CIE 1931 XYZ color space](http://en.wikipedia.org/wiki/CIE_1931_color_space), which can predict which [spectral power distributions](http://en.wikipedia.org/wiki/Spectral_power_distribution) will be perceived as the same color (see [metamerism](http://en.wikipedia.org/wiki/Metamerism_(color))), but which is not particularly [perceptually uniform](http://en.wikipedia.org/w/index.php?title=Perceptual_uniformity&action=edit&redlink=1).[[3]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-2) Strongly influenced by the [Munsell color system](http://en.wikipedia.org/wiki/Munsell_color_system), the intention of both “Lab” color spaces is to create a space which can be computed via simple formulas from the *XYZ* space, but is more perceptually uniform than *XYZ*.[[4]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-3) *Perceptually uniform* means that a change of the same amount in a color value should produce a change of about the same visual importance. When storing colors in limited precision values, this can improve the reproduction of tones. Both Lab spaces are relative to the [white point](http://en.wikipedia.org/wiki/White_point) of the *XYZ* data they were converted from. Lab values do not define absolute colors unless the white point is also specified. Often, in practice, the white point is assumed to follow a standard and is not explicitly stated (e.g., for "absolute colorimetric" [rendering intent](http://en.wikipedia.org/wiki/Rendering_intent) ICC *L\*a\*b\** values are relative to [CIE standard illuminant](http://en.wikipedia.org/wiki/Standard_illuminant) D50, while they are relative to the unprinted substrate for other rendering intents).[[5]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-ICC4-4)

The lightness correlate in CIELAB is calculated using the cube root of the [relative luminance](http://en.wikipedia.org/wiki/Relative_luminance), and using the square root in Hunter Lab (an older approximation).[[6]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-versus-5) Except where data must be compared with existing Hunter *L*,*a*,*b* values, it is recommended that CIELAB be used for new applications.[[6]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-versus-5)

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| Contents  * [1 Advantages of Lab](http://en.wikipedia.org/wiki/Lab_color_space#Advantages_of_Lab) * [2 Which "Lab"?](http://en.wikipedia.org/wiki/Lab_color_space#Which_.22Lab.22.3F) * [3 CIE 1976 (L\*, a\*, b\*) color space (CIELAB)](http://en.wikipedia.org/wiki/Lab_color_space#CIE_1976_.28L.2A.2C_a.2A.2C_b.2A.29_color_space_.28CIELAB.29)   + [3.1 Measuring differences](http://en.wikipedia.org/wiki/Lab_color_space#Measuring_differences)   + [3.2 RGB and CMYK conversions](http://en.wikipedia.org/wiki/Lab_color_space#RGB_and_CMYK_conversions)   + [3.3 Range of L\*a\*b\* coordinates](http://en.wikipedia.org/wiki/Lab_color_space#Range_of_L.2Aa.2Ab.2A_coordinates)   + [3.4 CIE XYZ to CIE L\*a\*b\* (CIELAB) and CIELAB to CIE XYZ conversions](http://en.wikipedia.org/wiki/Lab_color_space#CIE_XYZ_to_CIE_L.2Aa.2Ab.2A_.28CIELAB.29_and_CIELAB_to_CIE_XYZ_conversions)     - [3.4.1 The forward transformation](http://en.wikipedia.org/wiki/Lab_color_space#The_forward_transformation)     - [3.4.2 The reverse transformation](http://en.wikipedia.org/wiki/Lab_color_space#The_reverse_transformation) * [4 Hunter Lab Color Space](http://en.wikipedia.org/wiki/Lab_color_space#Hunter_Lab_Color_Space)   + [4.1 Approximate formulas for Ka and Kb](http://en.wikipedia.org/wiki/Lab_color_space#Approximate_formulas_for_Ka_and_Kb)   + [4.2 The Hunter Lab Color Space as an Adams chromatic valence space](http://en.wikipedia.org/wiki/Lab_color_space#The_Hunter_Lab_Color_Space_as_an_Adams_chromatic_valence_space) * [5 References](http://en.wikipedia.org/wiki/Lab_color_space#References) * [6 External links](http://en.wikipedia.org/wiki/Lab_color_space#External_links) |

## Advantages of Lab

Unlike the [RGB](http://en.wikipedia.org/wiki/RGB_color_model) and [CMYK](http://en.wikipedia.org/wiki/CMYK_color_model) color models, *Lab* color is designed to approximate human vision. It aspires to perceptual uniformity, and its *L* component closely matches human perception of lightness. It can thus be used to make accurate color balance corrections by modifying output [curves](http://en.wikipedia.org/wiki/Curve_(tonality)) in the *a* and *b* components, or to adjust the lightness contrast using the *L* component. In RGB or CMYK spaces, which model the output of physical devices rather than human visual perception, these transformations can only be done with the help of appropriate [blend modes](http://en.wikipedia.org/wiki/Blend_modes) in the editing application.

Because *Lab* space is much larger than the [gamut](http://en.wikipedia.org/wiki/Gamut) of computer displays, printers, or even human vision, a bitmap image represented as Lab requires more data per pixel to obtain the same precision as an RGB or CMYK bitmap. In the 1990s, when computer hardware and software was mostly limited to storing and manipulating 8 bit/channel bitmaps, converting an RGB image to Lab and back was a lossy operation. With 16 bit/channel support now common, this is no longer such a problem.

Additionally, many of the “colors” within Lab space fall outside the gamut of human vision, and are therefore purely imaginary; these “colors” cannot be reproduced in the physical world. Though color management software, such as that built in to image editing applications, will pick the closest in-gamut approximation, changing lightness, colorfulness, and sometimes hue in the process, author [Dan Margulis](http://en.wikipedia.org/wiki/Dan_Margulis) claims that this access to [imaginary colors](http://en.wikipedia.org/wiki/Imaginary_color) is useful going between several steps in the manipulation of a picture.[[7]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-margulis-6)

## Which "Lab"?

Some specific uses of the abbreviation in software, literature etc.

* In [Adobe Photoshop](http://en.wikipedia.org/wiki/Adobe_Photoshop), image editing using "Lab mode" is CIELAB D50.[[7]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-margulis-6)[[8]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-7)
* In [ICC profiles](http://en.wikipedia.org/wiki/ICC_profile), the "Lab color space" used as a [profile connection space](http://en.wikipedia.org/wiki/Color_management#Profile_Connection_Space) is CIELAB D50.[[5]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-ICC4-4)
* In [TIFF](http://en.wikipedia.org/wiki/TIFF) files, the CIELAB color space may be used.[[9]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-TIFF6-8)
* In [PDF](http://en.wikipedia.org/wiki/PDF) documents, the "Lab color space" is CIELAB.[[10]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-9)[[11]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-10)

## CIE 1976 (*L\**, *a\**, *b\**) color space (CIELAB)

**CIE *L\*a\*b\** (CIELAB)** is the most complete[[*citation needed*](http://en.wikipedia.org/wiki/Wikipedia:Citation_needed)] [color space](http://en.wikipedia.org/wiki/Color_space) specified by the [International Commission on Illumination](http://en.wikipedia.org/wiki/International_Commission_on_Illumination) (*Commission Internationale d'Eclairage*, hence its *CIE* [initialism](http://en.wikipedia.org/wiki/Initialism)). It describes all the colors visible to the human eye and was created to serve as a device independent model to be used as a reference.

The three coordinates of CIELAB represent the lightness of the color (***L\**** = 0 yields black and ***L\**** = 100 indicates diffuse white; specular white may be higher), its position between red/magenta and green (***a\****, negative values indicate green while positive values indicate magenta) and its position between yellow and blue (***b\****, negative values indicate blue and positive values indicate yellow). The asterisk (\*) after *L*, *a* and *b* are part of the full name, since they represent L\*, a\* and b\*, to distinguish them from Hunter's L, a and b, described below.

Since the *L\*a\*b\** model is a three-dimensional model, it can only be represented properly in a three-dimensional space.[[12]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-11) Two-dimensional depictions are chromaticity diagrams: sections of the [color solid](http://en.wikipedia.org/wiki/Color_solid) with a fixed lightness. It is crucial to realize that the visual representations of the full [gamut](http://en.wikipedia.org/wiki/Gamut) of colors in this model are never accurate; they are there just to help in understanding the concept.

Because the red/green and yellow/blue opponent channels are computed as differences of lightness transformations of (putative) cone responses, CIELAB is a [chromatic value](http://en.wikipedia.org/wiki/Adams_chromatic_valence_color_space#Chromatic_value) color space.

A related color space, the [CIE 1976 (*L\**, *u\**, *v\**) color space](http://en.wikipedia.org/wiki/CIELUV_color_space), preserves the same *L\** as *L\*a\*b\** but has a different representation of the chromaticity components. CIELUV can also be expressed in cylindrical form (CIELCH), with the chromaticity components replaced by correlates of [chroma](http://en.wikipedia.org/wiki/Chroma) and [hue](http://en.wikipedia.org/wiki/Hue).

Since CIELAB and CIELUV, the CIE has been incorporating an increasing number of [color appearance phenomena](http://en.wikipedia.org/w/index.php?title=Color_appearance_phenomena&action=edit&redlink=1) into their models, to better model color vision. These [color appearance models](http://en.wikipedia.org/w/index.php?title=Color_appearance_model&action=edit&redlink=1), of which CIELAB, although not designed as [[13]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-12) can be seen as a simple example,[[14]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-13) culminated with [CIECAM02](http://en.wikipedia.org/wiki/CIECAM02).

### Measuring differences

*Main article:* [*Color difference*](http://en.wikipedia.org/wiki/Color_difference)

The nonlinear relations for *L\**, *a\**, and *b\** are intended to mimic the nonlinear response of the eye. Furthermore, uniform changes of components in the *L\*a\*b\** color space aim to correspond to uniform changes in perceived color, so the relative perceptual differences between any two colors in *L\*a\*b\** can be approximated by treating each color as a point in a three dimensional space (with three components: *L\**, *a\**, *b\**) and taking the [Euclidean distance](http://en.wikipedia.org/wiki/Euclidean_distance) between them.[[15]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-Jain89-14)

### RGB and CMYK conversions

There are no simple formulas for conversion between [RGB](http://en.wikipedia.org/wiki/RGB_color_model) or [CMYK](http://en.wikipedia.org/wiki/CMYK_color_model) values and *L\*a\*b\**, because the RGB and CMYK color models are device dependent. The RGB or CMYK values first need to be transformed to a specific [absolute color space](http://en.wikipedia.org/wiki/Absolute_color_space), such as [sRGB](http://en.wikipedia.org/wiki/SRGB_color_space) or [Adobe RGB](http://en.wikipedia.org/wiki/Adobe_RGB_color_space). This adjustment will be device dependent, but the resulting data from the transform will be device independent, allowing data to be transformed to the [CIE 1931 color space](http://en.wikipedia.org/wiki/CIE_1931_color_space) and then transformed into *L\*a\*b\**.

### Range of L\*a\*b\* coordinates

As mentioned previously, the L\* coordinate ranges from 0 to 100. The possible range of a\* and b\* coordinates depends on the color space that one is converting from.

### CIE XYZ to CIE *L\*a\*b\** (CIELAB) and CIELAB to CIE XYZ conversions

#### The forward transformation

L^* = 116\,f(Y/Y_n) - 16

a^* = 500\,[f(X/X_n) - f(Y/Y_n)]

b^* = 200\,[f(Y/Y_n) - f(Z/Z_n)]

where

f(t) = \begin{cases} 
t^{1/3} & t > (6/29)^3 \\
\frac{1}{3} \left( \frac{29}{6} \right)^2 t + \frac{4}{29} & \mbox{otherwise}
\end{cases}

Here *Xn*, *Yn* and *Zn* are the CIE XYZ tristimulus values of the reference [white point](http://en.wikipedia.org/wiki/White_point) (the subscript n suggests "normalized").

The division of the *f*(*t*) function into two domains was done to prevent an infinite slope at *t* = 0. *f*(*t*) was assumed to be linear below some *t* = *t*0, and was assumed to match the *t*1 / 3 part of the function at *t*0 in both value and slope. In other words:

|  |  |  |  |
| --- | --- | --- | --- |
| t_0^{1/3}\, | =\, | a t_0 + b\, | (match in value) |
| 1/(3t_0^{2/3})\, | =\, | a\, | (match in slope) |

The value of *b* was chosen to be 16/116. The above two equations can be solved for *a* and *t*0:

|  |  |  |  |
| --- | --- | --- | --- |
| a\, | =\, | 1/(3\delta^2)\, | = 7.787037\cdots |
| t_0\, | =\, | \delta^3\, | = 0.008856\cdots |

where δ = 6 / 29.[[16]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-15) Note that the slope at the join is *b* = 16 / 116 = 2δ / 3.

#### The reverse transformation

The reverse transformation is as follows (with δ = 6 / 29 as mentioned above):

1. define f_y\ \stackrel{\mathrm{def}}{=}\  (L^*+16)/116
2. define f_x\ \stackrel{\mathrm{def}}{=}\  f_y+a^*/500
3. define f_z\ \stackrel{\mathrm{def}}{=}\  f_y-b^*/200
4. if f_y > \delta\,then Y=Y_nf_y^3\,   else Y=(f_y-16/116)3\delta^2Y_n\,
5. if f_x > \delta\,then X=X_nf_x^3\,   else X=(f_x-16/116)3\delta^2X_n\,
6. if f_z > \delta\,then Z=Z_nf_z^3\,   else Z=(f_z-16/116)3\delta^2Z_n\,

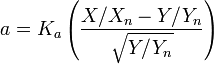
## Hunter Lab Color Space

***L*** is a correlate of [lightness](http://en.wikipedia.org/wiki/Lightness_(color)), and is computed from the *Y* [tristimulus](http://en.wikipedia.org/wiki/Tristimulus) value using Priest's approximation to [Munsell](http://en.wikipedia.org/wiki/Munsell) value:

L=100\sqrt{Y \over Y_n}

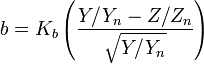
where *Yn* is the *Y* [tristimulus](http://en.wikipedia.org/wiki/Tristimulus) value of a specified white object. For surface-color applications, the specified white object is usually (though not always) a hypothetical material with unit reflectance and which follows [Lambert's law](http://en.wikipedia.org/wiki/Lambert%27s_law). The resulting *L* will be scaled between 0 (black) and 100 (white); roughly ten times the [Munsell](http://en.wikipedia.org/wiki/Munsell) value. Note that a medium lightness of 50 is produced by a luminance of 25, since 100 \sqrt{25/100}=100 \cdot 1/2

***a*** and ***b*** are termed [opponent color](http://en.wikipedia.org/wiki/Opponent_color) axes. ***a*** represents, roughly, Redness (positive) versus Greenness (negative). It is computed as:



where *Ka* is a coefficient which depends upon the illuminant (for D65, Ka is 172.30; see approximate formula below) and *Xn* is the *X* [tristimulus](http://en.wikipedia.org/wiki/Tristimulus) value of the specified white object.

The other opponent color axis, ***b***, is positive for yellow colors and negative for blue colors. It is computed as:



where *Kb* is a coefficient which depends upon the illuminant (for [D65](http://en.wikipedia.org/wiki/D65), *Kb* is 67.20; see approximate formula below) and *Zn* is the *Z* [tristimulus](http://en.wikipedia.org/wiki/Tristimulus) value of the specified white object.[[17]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-16)

Both *a* and *b* will be zero for objects which have the same [chromaticity](http://en.wikipedia.org/wiki/Chromaticity) coordinates as the specified white objects (i.e., achromatic, grey, objects).

### Approximate formulas for *Ka* and *Kb*

In the previous version of the Hunter *Lab* color space, *Ka* was 175 and *Kb* was 70. Apparently, Hunter Associates Lab discovered that better agreement could be obtained with other color difference metrics, such as CIELAB (see above) by allowing these coefficients to depend upon the illuminants. Approximate formulæ are:

K_a\approx\frac{175}{198.04}(X_n+Y_n)

K_b\approx\frac{70}{218.11}(Y_n+Z_n)

which result in the original values for Illuminant *C*, the original illuminant with which the *Lab* color space was used.

### The Hunter Lab Color Space as an Adams chromatic valence space

[Adams chromatic valence color spaces](http://en.wikipedia.org/wiki/Adams_chromatic_valence_color_space) are based on two elements: a (relatively) uniform lightness scale, and a (relatively) uniform [chromaticity](http://en.wikipedia.org/wiki/Chromaticity) scale.[[18]](http://en.wikipedia.org/wiki/Lab_color_space#cite_note-Adams1942-17) If we take as the uniform lightness scale Priest's approximation to the [Munsell](http://en.wikipedia.org/wiki/Munsell) Value scale, which would be written in modern notation:

L=100\sqrt{Y \over Y_n}

and, as the uniform chromaticity coordinates:

c_a=\frac{X/X_n}{Y/Y_n}-1=\frac{X/X_n-Y/Y_n}{Y/Y_n}

c_b=k_e\left(1-\frac{Z/Z_n}{Y/Y_n}\right)=k_e\frac{Y/Y_n-Z/Z_n}{Y/Y_n}

where *ke* is a tuning coefficient, we obtain the two chromatic axes:

a=K\cdot L\cdot c_a=K\cdot 100\sqrt{Y/Y_n}\frac{X/X_n-Y/Y_n}{Y/Y_n}=K\cdot 100\frac{X/X_n-Y/Y_n}{\sqrt{Y/Y_n}}

and

b=K\cdot L\cdot c_b=K\cdot k_e\cdot 100\sqrt{Y/Y_n}\frac{Y/Y_n-Z/Z_n}{Y/Y_n}=K\cdot k_e\cdot 100\frac{Y/Y_n-Z/Z_n}{\sqrt{Y/Y_n}}

which is identical to the Hunter *Lab* formulae given above if we select *K* = *Ka* / 100 and *ke* = *Kb* / *Ka*. Therefore, the Hunter Lab color space is an [Adams chromatic valence color space](http://en.wikipedia.org/wiki/Adams_chromatic_valence_color_space).

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## External links

* [Demonstrative color conversion applet](http://www.cs.rit.edu/~ncs/color/a_spaces.html)
* [CIELAB Color Space](http://www.fho-emden.de/~hoffmann/cielab03022003.pdf) by Gernot Hoffmann, includes explanations of L\*a\*b\* conversion formulae, graphical depictions of various gamuts plotted in L\*a\*b\* space, and PostScript code for performing the color transformations.