Farbe

Light Sources
Color of Light Sources

- light color depends on lamp technology

normal bulb
daylight bulb
mercury lamp [Quecksilber]
low pressure sodium lamp [Natrium]
high pressure sodium lamp [Natrium]
Correlated Color Temperature (CCT)

- The correlated color temperature of a light source is the temperature of an ideal black-body radiator that radiates light of as similar hue as possible to that light source.
Color Rendering Index (CRI) $R_a$

- CRI \textit{[Farbwiedergabeindex]} describes the quality of illuminants on the color appearance of objects compared to standard light of the same correlated color temperature (CCT)
- up to 5000 K: reference = blackbody radiator
- over 5000 K: reference = normed daylight $D_{xx}$
- Ø of 14 Munsell (also DIN) colors (general CRI: 8 of these colors)
- $R_a \leq 100$ (100 means perfect, ~50 for old fluorescent lamps, can also be negative!)
DIN Colors for Color Rendering Index

14 test color samples

#1 light greyish red
#2 dark greyish yellow
#3 strong yellow green
#4 moderate yellowish green
#5 light bluish green
#6 light blue
#7 light violet
#8 light reddish purple

#9 strong red
#10 strong yellow
#11 strong green
#12 strong blue
#13 light yellowish pink
#14 moderate olive green

additional 6 colors for full CRI

8 colors used for general CRI
## Color Rendering Index Examples

<table>
<thead>
<tr>
<th>Light Source</th>
<th>CRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>incandescent light bulb</td>
<td>up to 100</td>
</tr>
<tr>
<td>white LED</td>
<td>80 – 95</td>
</tr>
<tr>
<td>fluorescent lamp</td>
<td>50 – 90</td>
</tr>
<tr>
<td>mercury vapor lamp</td>
<td>45</td>
</tr>
<tr>
<td>low pressure sodium vapor lamp</td>
<td>-44 – 30</td>
</tr>
</tbody>
</table>
Lamps

- combustion lamp
- incandescent light bulb
- tungsten halogen lamp
- gas discharge lamp
- high intensity discharge lamp
- electric arc lamp
- induction lamp
- LED lamp
- …
Combustion Lamps

- **candles**: ~13 lumen, 40 watts of heat
- **gas light**: burning of hydrogen, methane, propane, ...
- **kerosene (paraffin) lantern**
- **oil light**: > 5000 years
- **torch**
- ...

the only lamps until after 1850!
Combustion Light Color

for flames with burning carbon particles

- **red**
  - just visible: 525° C (800 K)
  - dull: ~700° C (1000 K) [düster]
  - cherry, full: ~900° C (1200 K)

- **orange**
  - deep: ~1100° C (1400 K)
  - clear: ~1200° C (1500 K)

- **yellow / white**
  - bright: ~1400° C (1700 K)
  - dazzling: ~1500° C (1800 K) [grell]
Incandescent Light Bulb

- glowing tungsten filament → black body radiation
- clear incandescent bulb: CRI 100
- color temperature: heat in K

<table>
<thead>
<tr>
<th>power(W)</th>
<th>output(lm)</th>
<th>efficacy(lm/W)</th>
<th>CCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>100</td>
<td>6.7</td>
<td>2500 K</td>
</tr>
<tr>
<td>40</td>
<td>400</td>
<td>10</td>
<td>2600 K</td>
</tr>
<tr>
<td>60</td>
<td>700</td>
<td>11.5</td>
<td>2700 K</td>
</tr>
<tr>
<td>100</td>
<td>1400</td>
<td>14</td>
<td>2800 K</td>
</tr>
<tr>
<td>200</td>
<td>3000</td>
<td>15</td>
<td>3000 K</td>
</tr>
</tbody>
</table>

(for 230V; efficacy for 110 V is ~20% higher)
Incandescent Lamp

Nitrogen or argon gas

Filament

Lead wires

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Tungsten Halogen Lamp  [Halogenglühlampe]

- tungsten filament + halogen gas added (iod)
- halogen cycle chemical reaction redeposits evaporated tungsten back on the filament
- increased life, less blackening, smaller lamps
- higher temperatures (up to 3100 K)
- $\rightarrow$ higher efficacy ($\sim +15\%$)
Fluorescent Lamp  [Leuchtstoffröhre]

- is a gas discharge lamp
- electricity excites mercury vapor
- fluorescent coating: UV → visible light
- luminous efficacy 60-90 lm/W
- high luminous efficiency (~22%)
- high lamp life (10 x incandescent lamp)
- low aging
- CRI 50-90 (medium color rendering index)
- sizes T12, T8, T5 (Tx = x/8 inch diameter)
Flourescent Tube Lamp

Flourescent Tube Lamp

Mercury and inert gases

Phosphor coating

Base with bi-pin plug

© Michigan Country Lines
Fluorescent Lamp  [Leuchtstoffröhre]

without phosphor coating:

with phosphor coating:

different phosphors define different CCT

© physikdidaktik.uni-karlsruhe.de
- low press. discharge lamp
- uses sodium vapor
- no fluorescent coating
- lum. efficacy ~200 lm/W
- very high lamp life (30 x incandescent lamp)
- CRI -44+ (very bad color rendering index)
- almost monochromatic at 589 nm → no colors!
Metal Halide Lamp  [Halogenmetalldampflampe]

- electric light that produces light by an electric arc through a gaseous mixture of vaporized mercury and metal halides (compounds of metals with bromine or iodine). It is a type of high-intensity gas discharge lamp (HID).

- 95 lm/W,  CCT: 3000-7000 K,  CRI: 65-96
Induction Light  [Induktionslampe]

- Power required to generate light is transferred from outside the lamp envelope to inside via electromagnetic fields, in contrast with a typical electrical lamp that uses electrical connections through the lamp envelope to transfer power.
  - High lamp life
  - High efficiency
  - Low aging
LED Lamp

- light-emitting diode
- luminous efficacy up to 250 lm/W
- very high lamp life (50 x incandescent lamp)
- CRI 80-95 (good color rendering index)
- combinations produce any color temperature
Lamp Aging

- all lamps lose brightness during their life

Typical Lumen Maintenance Values for Various Light Sources

- 100W Incandescent
- 50W Tungsten Halogen
- 400W Metal Halide
- 42W CFL
- 32W T8 Fluorescent
- 5-mm LED
- High-Power LED
## Overview: Some Typical Values

<table>
<thead>
<tr>
<th>Lighting Source</th>
<th>CCT</th>
<th>CRI</th>
<th>lm/W</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>combustion</td>
<td>1800</td>
<td>100</td>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>incandescent</td>
<td>2700</td>
<td>100</td>
<td>13</td>
<td>1000 h</td>
</tr>
<tr>
<td>tungsten halogen</td>
<td>3000</td>
<td>100</td>
<td>16</td>
<td>4000 h</td>
</tr>
<tr>
<td>fluorescent</td>
<td>var.</td>
<td>70</td>
<td>70</td>
<td>10000 h</td>
</tr>
<tr>
<td>low press. sodium</td>
<td>1800</td>
<td>-44</td>
<td>200</td>
<td>30000 h</td>
</tr>
<tr>
<td>induction</td>
<td>var.</td>
<td>70</td>
<td>80</td>
<td>100000 h</td>
</tr>
<tr>
<td>LED</td>
<td>var.</td>
<td>var.</td>
<td>&gt;60</td>
<td>500000 h</td>
</tr>
</tbody>
</table>