Radiometry vs. Photometry

**Radiometry** -- the measurement and specification of the power (energy) of a source of electromagnetic radiation.
- total energy or numbers of quanta

**Photometry** -- the measurement and specification of a light source in terms of its ability to produce a visual sensation.
- intensity as relevant to human vision

Radiometric and photometric units

Radiometric units measure the total energy of light from a source, or falling on a surface. Photometric units are similar, but are compensated by the human spectral luminous efficiency curves $V_\lambda$ or $V'_{\lambda}$.

<table>
<thead>
<tr>
<th>Radiometric term</th>
<th>Symbol</th>
<th>Units</th>
<th>Photometric term</th>
<th>Symbol</th>
<th>Comparable Units (Abbreviations Indicated in Parentheses)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiant flux</td>
<td>$P$</td>
<td>watt</td>
<td>Luminous flux</td>
<td>$F$</td>
<td>lumen (lu)</td>
</tr>
<tr>
<td>Radiant intensity</td>
<td>$J$</td>
<td>watt/(\omega)</td>
<td>Luminous intensity</td>
<td>$I$</td>
<td>1 lu/(\omega)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Candlepower</td>
<td></td>
<td>1 candle (c) Now called “Candela,” abbreviated cd</td>
</tr>
<tr>
<td>Irradiance</td>
<td>$H$</td>
<td>watt/m(^2)</td>
<td>Illuminance</td>
<td>$E$</td>
<td>1 lu/m(^2) = 1 lux</td>
</tr>
<tr>
<td>Radiance</td>
<td>$N$</td>
<td>watt/(\omega)/m(^2)</td>
<td>Luminance</td>
<td>$L$</td>
<td>1 lu/(\omega)/m(^2) = 1 c/m(^2) = 0.3142 millilambert (mL) = 0.2919 foot-lambert (ft-L)</td>
</tr>
<tr>
<td>Retinal illuminance</td>
<td>$T$</td>
<td></td>
<td></td>
<td></td>
<td>Troland = cd/m(^2) x pupil area mm(^2)</td>
</tr>
</tbody>
</table>
**Radiant and luminous Flux**

The total emitted light from a point source is described as radiant or luminous **flux**.

Radiometric Units

watts = joules / sec

Photometric Units

lumens

Luminous flux is used to specify light sources, like standard bulbs. The wattage of a bulb describes the electrical power it consumes, not the light energy emitted. A 60 watt incandescent bulb, and a 15 watt compact fluorescent bulb both emit about 900 lumens.

**Radiant and Luminous Intensity**

The total emitted light from a point source in a particular direction is described as radiant or luminous **intensity**. It is measured in flux per unit solid angle, or **steradian** (\(\omega\) ”omega”).

Radiometric Units

watts/ \(\omega\)

Photometric Units

Candela = lumen/ \(\omega\)

The Candela is the SI base unit of photometry. It is based on an old unit called the candle, but is now defined as 1/683 W/ \(\omega\) at 555 nm.
Irradiance and Illuminance

The total light falling on a surface is described by **Irradiance** and **Illuminance**.

**Photometric Units**
- Lumens/m$^2$

**Radiometric Units**
- Watts/m$^2$

Irradiance/illuminance takes into account all light coming from all directions, regardless of the source.

**Retinal illuminance** is a special case, it describes the amount of light falling on a patch of retina and is measured in **Trolands**.

Radiance and Luminance

The total emitted light in a particular direction from an extended source is described as **radiance** or **luminance**. It includes both the area of the source and the solid angle over which the light is captured.

**Photometric Units**
- Candela/m$^2$ (cd/m$^2$)

**Radiometric Units**
- Watts/ω/m$^2$

Luminance is used most often in Vision Science, and there are many units to describe it.
- 1 nit = 1 cd/m$^2$
- 1 Lambert = 3183 cd/m$^2$
- 1 apostilb = .3183 cd/m$^2$
- 1 foot-lambert = 3.43 cd/m$^2$

http://www.unitconversion.org/unit_converter/luminance.html
Luminance, Brightness, Lightness

**Luminance** is a physical measurement of light energy, adjusted for the sensitivity of the eye to different wavelength.

**Brightness** is the perception of light level. It depends on more than just the luminance energy, it also depends on the context of the whole scene. White paper in sunlight looks brighter than white paper in moonlight.

**Lightness** is the perception of a surface color in terms of black, white, and shades of gray. A white paper still looks like a white paper inside or outside.

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Luminance ≠ Brightness!

The luminance of the letter E on each side is the same. The apparent brightness is different because of contrast effects. In order to compare luminances with the eye, patches must be close together in space and/or time and then adjusted to have no difference. There are two common psychophysical methods to do **Photometry** with the eye. Minimally distinct border, and flicker photometry.
Shadows and perceived brightness

http://web.mit.edu/persci/people/adelson/checkershadow_illusion.html

Patches A and B appear to have different lightness. A is a gray square, B is a white square.

Patches A and B appear to have different brightness. B is in shadow, so it isn’t as bright as it could be, but it still looks a little brighter than A.

Patches A and B actually have the same luminance!

The brain uses shadows and shapes to adjust perception so that the true properties of the surface are seen.

Context effects on perception

http://web.mit.edu/persci/people/adelson/checkershadow_illusion.html

Removing the context information (shadows, edges, shapes) allows you to see that Patches A and B actually have the same luminance!

The brain uses shadows and other context info to adjust perception so that the true properties of the surface are seen.

The eye can make accurate luminance judgments if we remove the context! If A and B are close together, we are very very good at comparing luminance.
Luminance can be the same, even if color is different

The blue letters are all as bright as I can make them. The yellow background goes from zero to 2/3 maximum. Somewhere in the middle, the blue and yellow have the same luminance. The color difference allows you to see the letters, but they look lustrous or shimmery at “iso-luminance”.

Photometric Brightness Match

Intensity and spectral composition of the reference light is fixed. The subject adjusts the intensity of the test light until it matches reference light.
Minimally Distinct Borders
Matching Photopic Lights

The goal is to adjust the relative intensities until the border appears “fuzzy” compared to other settings.

Heterochromatic Flicker Photometry

Temporally exchange the test wavelength with the standard (about 10-15 Hz). The combination produces color fusion. The goal is to adjust the intensity of the test wavelength to reduce the appearance of flickering.
Using the Scotopic Luminosity Function to equate the luminance of different wavelengths and calculate total luminance

To match a reference $\lambda_1$ light that had a radiant power of 10 watts:

Example 1: A test $\lambda_2$ light would have to a radiant power of 20 watts.
Example 2: A test $\lambda_3$ light would have a radiant power of 40 watts.

Example 3: the sum of 10 watts of $\lambda_2$ and 20 watts of $\lambda_3$.
\[ (.8 \times 10W = .4 \times 10W + .2 \times 20W) \]

Example 4: 5 watts of $\lambda_2$ and 30 watts of $\lambda_3$.
\[ (.8 \times 10W = .4 \times 5W + .2 \times 30W) \]

Abney’s Law of “Additivity”:
Overall luminance is the sum of each test light’s luminance.

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Photometric matching Demo
Scotopic Simulation
Photometric matching Demo
Red-Yellow

Photometric matching Demo
Blue-Yellow