# Light, LEDs, and Human perception.

SUMMARY: This handout contains a very brief and light (HA!) overview intended to help you understand how to choose a LED and what the values mean. An emphasis is placed on functional understanding over technical accuracy, as such **SOME INFORMATION MAY BE TECHNICALLY INCORRECT***.

## Terms that may be new to you:

**Black body radiation**: Light generated due to heat through collisions between atoms.

**Luminous intensity** or candela(cd): How bright an object appears to be when looking at it.

**Luminous flux** or lumen(lm): Total amount of perceived light put out by an object.

**Luminance** or candela per sq meter(nits): The amount of perceived light per surface area generated by looking at it.

## How bright is my light?

There are three ways in which the brightness of LEDs are measured, depending on how they are being used. As a single led being used as an indicator would usually be measured by candela. This is because your main concern is how bright the LED appears from the angles you are likely to view it. An array of LEDs forming a screen would be measured in nits because your eyes are going to see the average amount of light from an area. It doesn't matter how bright a dot is if it is really small.

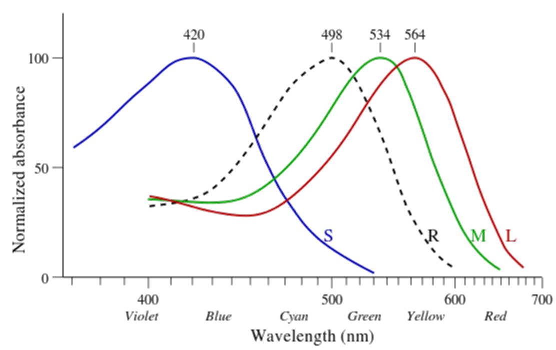
That may be a bit confusing, so let me give you an example. A laser would put out a lot of candela, if you looked directly into the beam you would most likely be blinded by even the weakest to lasers, but because the viewing angle is so low, the TOTAL amount of light (that is lumens) output by the laser isn't that much. A single spot is lit up quite a bit, but everything else is dark. Thus, if you want to light up your room, the candela put out by a light source doesn't matter because you aren't looking at at the light itself, but rather the reflection of that light from all the objects in the room. In this case you want to know the lumens, or total amount of light your source puts into the room.

What about nits? Consider the brightest object in the sky, the sun. As you are most likely aware there are much brighter stars out there (more candela) but they are so far away that they are hardly visible. They end up being the equivalent of tons of candela generated over a fraction of a $mm^2$ at a few meters away.

The good news is that these values can be converted, but the bad news is that you may need to use steradians(sr) to do so. This will be discussed during the presentation in response to question X but it is a bit outside the scope of what we are covering.

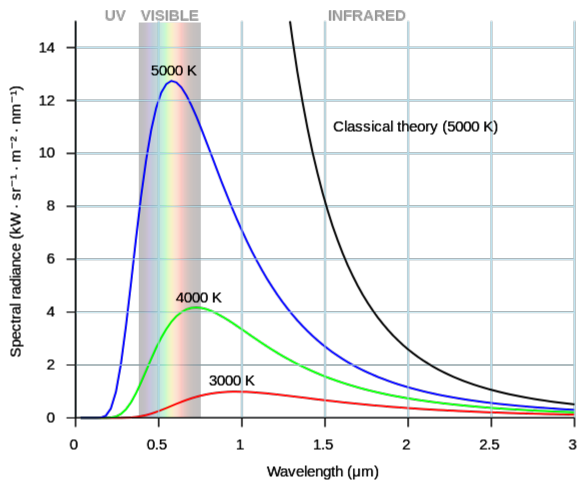
## Human perception of light.

You should note some key words in the definitions of the previous terms such as "perception." Humans can not see all wavelengths of light, and do not perceive all colors with the same intensity.




*Blatantly ripped from wikipedia [1]*

As it turns out the reason our eyes evolved for this part of the spectrum is because these end up being wavelengths that penetrate the best through the atmosphere and water.[2] But that is outside of the scope of this class as well. In the end what this means is that not all light is useful, incandescent light bulbs would be nearly 100% efficient if it was. Because incandescent bulbs use black body radiation, most of the light is emitted outside of the visible spectrum. You can increase the temperature in order to make the peak of the emission spectrum line up with human eyesight, but you are limited by the temperatures that materials are able to sustain, and even the best case (~7000K) isn't very efficient.




*Also ripped from wikipedia [3]*

The "Luminous efficacy" (think efficiency, but not not on a percent scale) of a light source is measured in lumens per watt and some rough values in useful (though technically somewhat wrong) terms are shown below. Most values are ripped from wikipedia. Theses are just ballpark figures and have limited meaning.

| | lm/W | "efficiency" |
|---|---|---|
| W light bulb | ~15 | 2.00% |
| Halogen | ~20 | 3.00% |
| Xenon | ~40 | 6.00% |
| Ideal black body radiator (~700K) | ~95 | 14.00% |
| Florescent | ~100 | 15.00% |
| "Good" LED | ~100 (and up) | 15.00% |
| 555 nm light source | ~700 | 100.00% |

## How LEDs work

Light emitting diodes work because electrons emit photons when they travel from higher energy levels to lower energy levels. The wavelength of the photon is determined by the change in energy between the to energy "bands." This so-called "band gap" can be adjusted in manufacturing to produce different colors of light. The easiest way to think of it is that each diode only emits one color of light if the production process is perfect. Because of this, LEDs can output only in the visible ranges and increase efficiency. A phosphorus coating is put on white LEDs to absorb the radiation and emit it over a broader (white) spectrum.

## Light quality

There is one last thing I would like to briefly touch on, and that is the quality of light. Because you only need to stimulate each of the cones to a similar amount to achieve the appearance of white light, the wavelengths in light that appears to be white can vary. Cheaper lights often have just a few peaks, one in each of the sensitive zones for each cone, and although the light may look the same in direct viewing, the amount of light that objects reflect will vary depending on the wavelength. In the worst case, it is technically possible for an object that looks green in "true" white light to look black if it absorbs the one green wavelength pout out by the light. Such a situation would never happen, but colors of objects will shift somewhat depending on the lighting. This is (I expect) the main reason why people dislike CFL, as the spectrum emitted is *usually* terrible.

**SOME INFORMATION MAY BE TECHNICALLY INCORRECT*** or, at the very least, interpenetrated in a manner that is incorrect. At two and a half pages, this is already much longer than I wanted it to be. If I was to fully explain and quantify everything it would be two and a half thousand. This should, however, give you a basic understanding of the topic provided you don't take an overly literal reading of this handout.

[1] http://en.wikipedia.org/wiki/File:Cone-response.svg (CC BY-SA 3.0)
After Bowmaker J.K. and Dartnall H.J.A., "Visual pigments of rods and cones in a human retina." *J. Physiol.* **298**: pp501-511 (1980).
[2] I think it is cool anyway, see:
http://en.wikipedia.org/wiki/Electromagnetic_absorption_by_water#mediaviewer/File:Absorption_spectrum_of_liquid_water.png
and
http://en.wikipedia.org/wiki/Visible_spectrum#mediaviewer/File:Atmospheric_electromagnetic_opacity.svg
[3] http://commons.wikimedia.org/wiki/File:Black_body.svg (public domain)