What does Color Temperature Mean?

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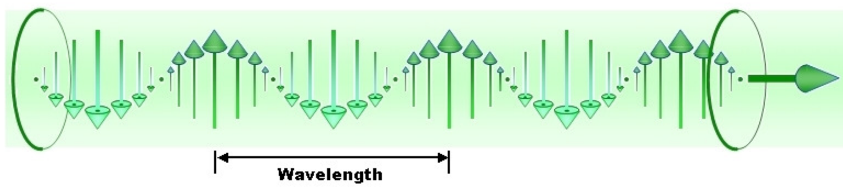
Picture yourself buying a fluorescent light at the local hardware store. The very first question you must answer is what color temperature do you need for your bulb? *Color temperature*?

This sounds as though color and temperature are related. Is a red rose merely pink when the temperature is 20° C (68° F) but purple when the temperature goes to 40° C (104° F)? No, certainly not. But the physical response a person has to light (Color) and the thermal effect on an object's light emission (Temperature) must be examined.

Basics: Light beams are made up of electric and magnetic fields pointing first one direction, reversing to point the other way, then repeating the pattern again.



Imagine taking a really fast photograph of a light beam. Suppose you could image the electric field. You might get a picture like this.

FIg. 1 If you could photograph the electric field in a beam of green light, it might look like this. (Entire pattern moving at c, the speed of light)

Wavelength of light – The distance between pattern repetition pointes in the freeze-action picture is called the wavelength. For our image of green light, the wavelength is about 520 nm (nano meters). For the metrically disadvantaged, a meter is 10% longer than a yard; 520 nm is 520 one-billionths of a meter, or 0.52 millionths, 0.000 000 540 m long. Each color in the rainbow has its own unique wavelength.

Light and sound waves are similar – Sound and light are similar in that they are both wave actions. Sound is also characterized by wavelengths (tones) and is capable of being produced by any combination of very long to very short wavelengths (low to high tones). Sometimes sound is described by its wavelength, sometimes its frequency; sometimes light is described by its wavelength, sometimes by its frequency (related to its energy).

Vision: We humans hear pure notes of *sound*. Our music is the pattern of varying intensity for every tone possible to make and hear. If, instead, we heard sound the way we see light, our music would be composed of a single chord of same three tones; the complex of musical experience would be formed from the different loudnesses of each tone. This difference between *hearing* notes but *seeing* chords confuses understanding of how we actually do see.

Human vision is due to photo-stimulation of rod or cone vision cells on the retina.

Cones are sensitive at low light intensities and do not function in full daylight, because their photo-sensitive chemicals are depleted. They provide night vision after the depleted chemicals have regenerated.

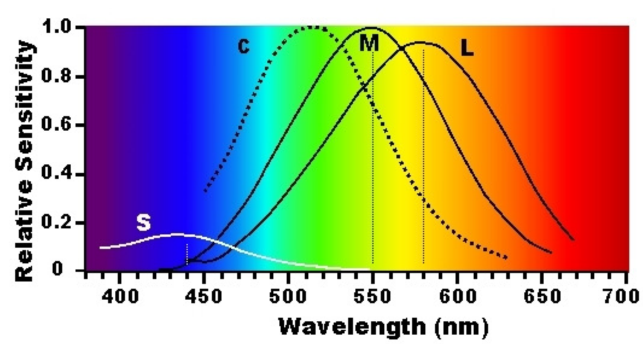


Fig 2. Response of rods and cones to light

Rods occur in 3 varieties: **L**, sensitive to long wave-lengths and peaking at orange (580 nm); **M**, functioning at medium wavelengths and peaking at lemon yellow-green (550 nm); **S**, responding to short wavelengths, peaking in blue (440 nm) and extending into deep violet. Rods are much less sensitive than cones, they only function during brighter conditions.

Details of the L, M and S rods can be seen in the graph. Both M and L rods are reported to have increased response near the peak of the S rods, but these data from human subjects are obviously difficult to acquire and high experimental repetitions cannot have been made. Treat the curves as probable average responses, not exact data-based results.

Final points about the Sensitivity data: Many graphs show the M, L and S as fractions of their own peak intensity and the graphs make them appear equally sensitive. M rods have the highest response to input light, L rods are about 8-10% less sensitive, and the blue-based S rods have a peak sensitivity of 15-20% that of M. So the graph shown here is essentially accurate. The CONE response curve is normalized to 100%. Including the C response could lead to false conclusions as to sensitivity compared with rods. This curve is included on the graph only to indicate the spectral region where cones respond.

A second point: certainly your vision sensitivity graph would differ from your friend's and from my own. Are all our thumbs the same? Are hair shades and textures identical? We almost certainly experience slightly different responses to that single chord (of L with M and S) that generates all color shades.
However: No *scientific* evidence has ever been reported for differences in male vs. female color response!

Vision sensitivity overall: Also called foveal sensitivity, this gives the color sensitivity of the average human eye. Peak sensitivity is midway between the L and M peaks, pretty much centered on yellow. There is a bump on the blue end caused by the S peak. We will use FIg. 3 later, when we discuss color temperature.

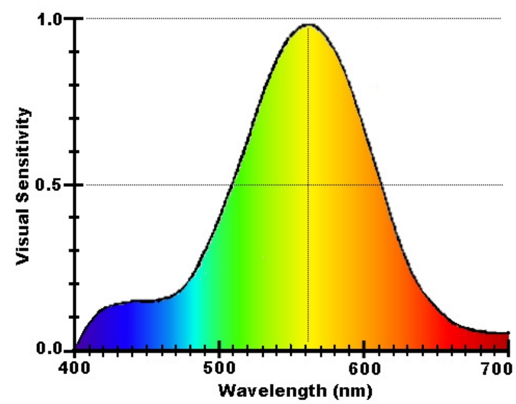


Fig 3. Overall response of eye to light

It is interesting that there has been so much controversy as to what color emergency equipment should have.

- Yellow or green are the easiest colors to see.
- A blue or dark red emergency vehicle would disappear as the light dims.
- Halogen car lights have been popular for upscale cars in recent years. These are blue lights. The light reflected back to the car must be very bright if the driver is to see hazards

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Blackbody emission spectra – everything radiates light. The molten iron in this picture generates a great deal of light, but nothing is burning. This means the iron is very hot.

Fig 4. Molten iron glows bright white

If you could not cool off as you stand in the sun, you would become hotter and hotter. Keep this up and you might reach spontaneous combustion temperature and burst into flame. Biological processes help you loose heat but your rate of heat absorption is also slowed by also by emitting "heat radiation," long wavelength light in a color called infra-red. You share this re-radiation with all physical objects. If absorbed heat was not re-emitted, then when you put pan in a medium temperature oven, it would just keep on absorbing energy and melt into puddle.

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It may sound strange to realize you are doing what a light bulb does, and, in fact, this was a major discovery 170 years ago.

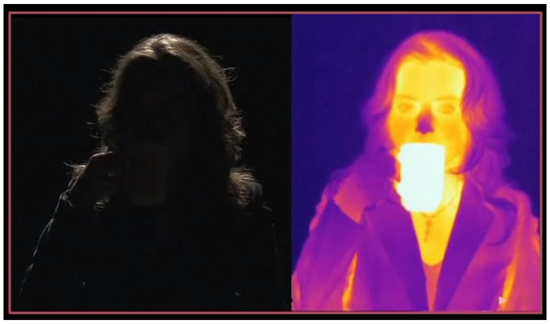

Fig 5. L: visual photo of subject in a darkened room
R: IR image taken at the same time

Fig. 5 is a picture of Dr. Amy Mainzer, Project Scientist for a major satellite program WISE, taken from NASA website discussing fundamental infra-red processes.

- The left image is from a visible light camera that photographed her in a darkened room. The camera recorded the visible light reflected off her. The image is essentially black, meaning that there is no contrast in the image to allow detail to show.
- The right image was taken with an IR camera that recorded her in infra-red light. She is glowing by the radiation process just discussed. Note her hot tea cup

IR surveys of the emission light from houses are good ways to check the insulation. Fig.6 is an infra-red image of an unheated house cooling down from the day's temperature. Hot spots indicate poor insulation, or a leaky roof.

Fig 6. uses an unfortunate visible color scale to show the temperature, but one that is pretty standard. The color for the temperature scales blue to red, for cold to hot. This is *not* the way nature actually conducts its thermal business.

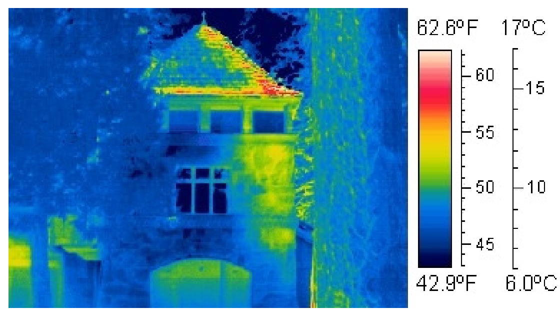

Fig 6. IR survey of house

Blackbody emission – This is emission of light due to its temperature. The name follows what happens if you put a cold object into a hot oven (no light sources). Good IR picture can be made of the object from its thermal glow. until it reaches the temperature of the interior of the oven, when it is bathed in the same radiation that it emits. At this point, there is is no image forming contrast. This is very much like the left photo above. Except for the dim light from above, there is no light source that gives the image contrast. The object in oven at full temperature is exactly like a black object in a black room. Hence, the thermal emission is called "backbody" emission. BB emission is the best self emission an object can do. It may not be reached for just any situation, but it serves as the standard reference to compare other emitting objects to.

The color of temperature When you look at this picture, you can easily identify the coolest and hottest parts. Your intuition says the coolest part of this fire picture is black; . dark red means hotter temperatures (actually, about 700º C or 1300º F). The brighter reds are hotter yet. The hottest part is in the white area, the yellow is slightly cooler … then orange then red. Your intuition is right for this color progression.

Fig 7. Hot and cold regions in a hearth are easy to identify

Not all color from a burning object is due to thermal emission, so you cannot accurately estimate flame temperature by its color. Chemical elements survive in a a burn to fairly high temperatures. A Bunsen burner uses methane which burns blue and is only a couple of times hotter than a hearth fire. Many gases burn blue, which partly indicates high temperatures (up to 3500º C) and partly the chemical makeup of the burning material.

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A plasma torch can reach temperatures exceeding 15 000º C (27,000º F). Material at this temperature will be a very intense blue, although it is 10× times lower than the temperature when chemical coloration effects cease to matter.

Fig 8. This extremely hot plasma torch is blue

The natural progression of color for blackbody (self) emission is from IR, through red, yellow, white, then blue. This is the follows the spectrum shown in the Vision section.

Physicists who thought they knew everything was surprised in 1870 when it was discovered that every object emitted light related to its thermal temperature. But they were in crisis mode by 1900 when they discovered they could not predict why. The accurate description of blackbody radiation was first described by Max Planck and Albert Einstein, who had to invent quantum physics to do so. A fairly complicated formula resulted from their non-intuitive analysis.

Fig. 9 shows that the thermal glow (blackbody emission) of an object at 2700 K has a wavelength peak value at 1000 nm (1 µm) but continues through out the long wavelength IR portion of the light spectrum. (*Spectrum* means a graph of light intensity vs. wavelength.) This is close to the blackbody radiation spectrum from our sun.

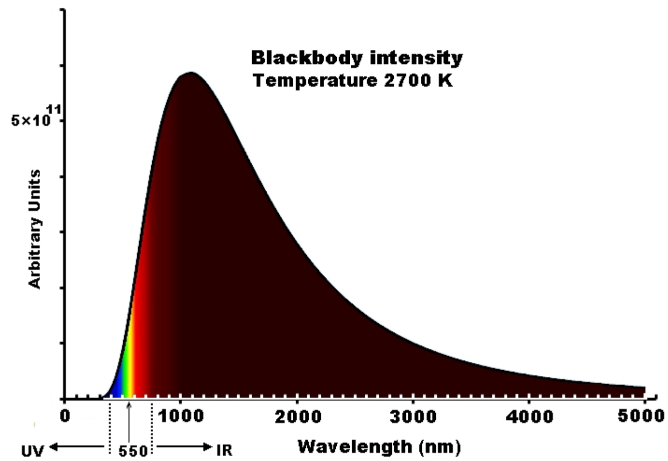

Fig. 9 Blackbody spectrum for an object at 2700 K temperature

> ***Units note:*** The Kelvin (absolute) temperature K is a fixed 273 degrees less than the related Celsius temperature. The degree sign is never shown for Kelvin temperatures.
>
> At 2700 K, C=2973º, only 10% greater than K. Our estimates will ignore the difference and use either interchangably.

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Finally we can put it all together Fig. 10 compares the visible light part of Fig. 9 with the foveal sensitivity of Fig. 3. The spectrum is low on the blue-sensitive side and grows quickly as we approach deep red sensitivity cutoff.

An object viewed in its 2700 K black body emission light will appear somewhat orange. If the light is bright enough, it will saturate the eye and appear white with yellow-orange tones.
This is the sun's visual color.

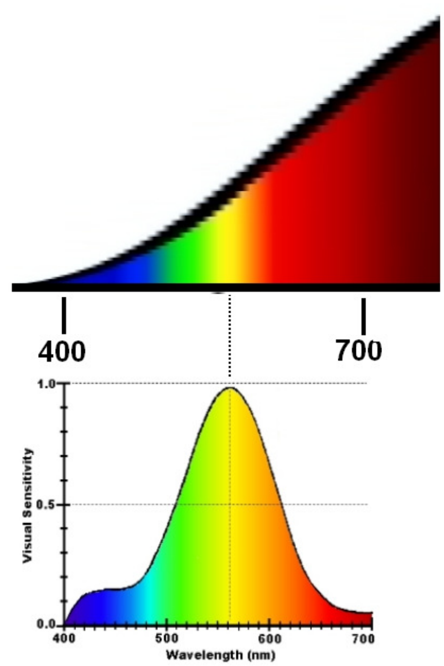

Fig. 10 Comparison of 2700 K bb emission and net sensitivity of eye

If you compare blackbody glow spectra to our visual sensitivity, you will come up with the plot of Figure 11.

Blackbody temperatures are marked along the curve and and overlays the visual color point.

This is result is from the 1931 report by the CIE (Commission Internationale de l'Eclairage). About the web link – Blackbody emission is sometimes called Planckian emission, as in this Wikipedia page.

For temperatures below 1500 K, most of the radiation is in the very deep IR, showing little overlap with visible sensitivity. The human body has peak radiation at 10 000 nm (10 µm).

For temperatures above 5000 K, high UV emission occurs and safety procedures are necessary.

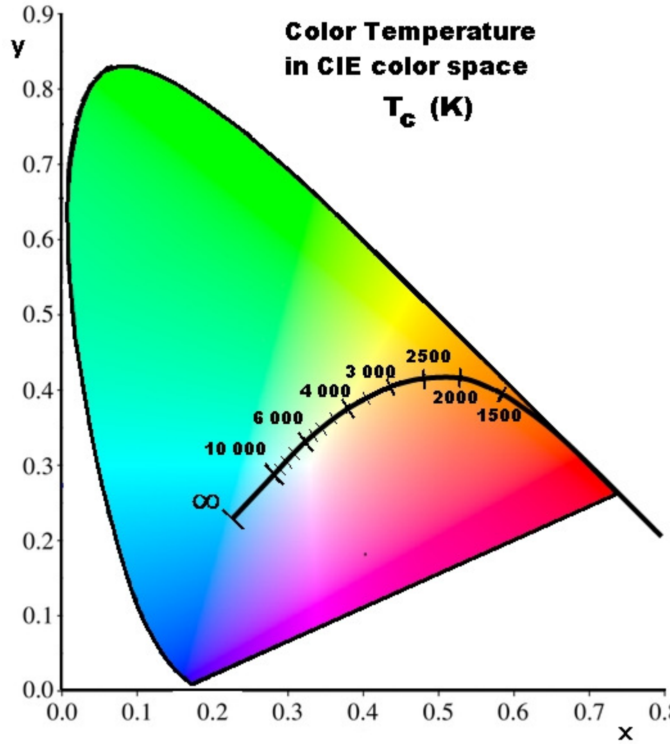

Fig. 11 Color Temperature for various BB temperatures

Blackbody emission is the most efficient radiation that occurs. It requires a special set up to produce and is used mainly as the basis for various comparisons.