

Photopic and Scotopic – The “eyes” have it

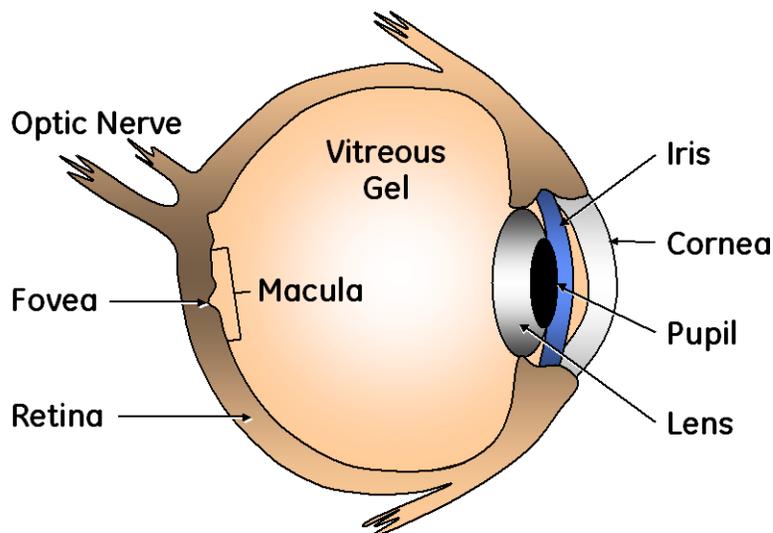
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In the human eye the perceived brightness of illumination depends of color. It takes more energy in the blue or red portion of the color spectrum to create the same sensation of brightness as in the yellow-green region.

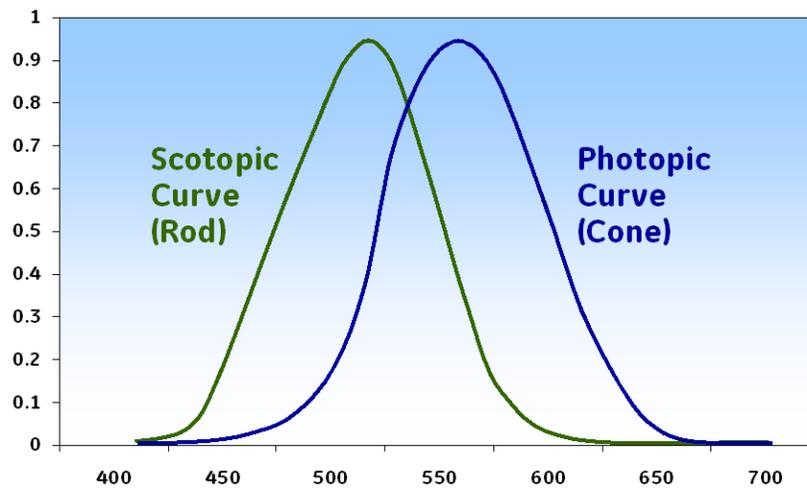
When it comes to sensing light in the human eye there are two main light-sensing cells called **rods** and **cones**. If one took a tube and looked straight ahead through it so that it allowed the field of view to be restricted 2 degrees, light photons would fall on the part of the eye called the fovea that consists mainly of **cones**. The peripheral area surrounding the fovea consists of both **rods** and **cones** with the **rods** outnumbering the **cones** about 10:1.

Human Eye - Cross Section



Cones have a peak response in the yellow-green region of about 555 nano-meters and **rods** have a peak response in the bluish-green area of about 505 nano-meters. Because both the **rods** and **cones** have been shown to have different sensitivities to colors they can be represented by two different sensitivity curves called Photopic Curves (representing the **cone**) and Scotopic Curves (representing the **rod**).

Scotopic / Photopic Curves



Years ago it was thought that the **cones** were responsible for daytime vision and **rods** for nighttime vision. Because of this, light meters that measure lighting levels such as footcandles, lumens, lux, etc. are weighted to the **cone** activated part of the eye ignoring the effect of **rod**-activated vision. But according to a study by Dr. Sam Berman and Dr. Don Jewett the roles of **rods** and **cones** are not exclusive but actually share responsibility depending on lighting conditions. Their experiments, sponsored by the US Dept. of Energy, show that **rods** do play a role in typical workplace lighting conditions. Thus the devices we use to measure light are not consistent with our human perception of lighting conditions. This has led to a movement among some lighting professionals to modify our criteria to include for **rod** sensitivity. If we use only **cone** sensitivity we would use the Photopic curve and likewise if we use only the **rod** sensitivity we would use the Scotopic curve. But if we want to be somewhere in between we could use a mixture of the two. Dr. Berman suggests multiplying the Photopic Lumen rating P by $(S/P)^n$ with P being Photopic lumens and S being Scotopic lumens. Thus if $n = 1$ we get pure Scotopic lumens and if $n = 0$ we get pure Photopic lumens and if n is between 0 and 1 we get a weighted average of the two. So, what value do we assign to n ?

Dr. Berman proposes that for reading tasks we should use $n = 0.78$ and for computer tasks $n = 1.0$. If we are merely interested in "perceived brightness" of a space Dr. Berman finds $n = 0.58$ to most correctly predict human response. He also shows that pupil size is dependent on Scotopic lumens and that the light our eye takes in is both foveal and peripheral and our perception of brightness is most likely going to be influenced by the peripheral Scotopic vision.

Pupil size plays an important role in vision in that smaller pupils results in better acuity, improves the depth of field and allows less accommodative response of the eye. Raising light levels will reduce the size of the pupil but this can add glare and waste energy. Another way to change pupil size is to change the color temperature of the light source. The higher the color temperature, the more the lighting is scotopically enhanced. This higher color temperature causes more of the **rods** to be

activated laying claim that an area may appear to be brighter even though a traditional photopically designed light meter might indicate otherwise.

So the controversy is what measurement system do we use? The current system based on the today's Photopic based footcandles or a "corrected" system of Photopic based footcandles $\times (S/P)^n$ ratio and using higher color temperatures light sources? One source that explores the later method (sometimes called Spectrally Enhanced Lighting) in depth with a feasibility study, an economic study and how to implement such a system can be found at http://www1.eere.energy.gov/buildings/spectrally_enhanced.html. In the end which method one chooses is entirely a personal choice.

It should be noted here that the IESNA (Illuminating Engineering Society of North America) has not (as of now, October 2008) endorsed the $(S/P)^n$ method and that GE Co. has no opinion about the validity of this method. GE recommends that you do not base an upgrade decision on calculations of the $(S/P)^n$ adjustment alone but that you actually try out an area to see if the light levels are adequate and the appearance is satisfactory before proceeding. GE publishes S/P ratios (scotopic to photopic lumens) for many light sources in its catalog. This is merely in response to the numerous inquiries that GE receives about this number. The CIE (Commission Internationale de l'Eclairage) originally established the photopic luminous efficiency function in 1924 and the scotopic luminous efficiency function in 1951. Photopic lumens and scotopic lumens are measurable using functions published by the CIE and the IESNA (Illuminating Engineering Society of North America).

GE has no expressed opinion on the validity of any calculations using S/P ratios.

Sources:

GE Lighting Assistant software (version 4.272 July 2008) - *The Photopic-Scotopic Debate (a summary)* by Sri Rahm, GE Co.

How the Eye sees Light and the S/P Ratio Debate by Michael Smith, GE Co.

Spectrally Enhanced Lighting Program Implementation for Energy Savings conducted by Pacific Northwest National Laboratory for the U.S. Department of Energy (August 2006)

U.S. Department of Energy – Energy Efficiency and Renewable Energy Building Technologies Program (May 2008)

Ruud LED by Ruud Lighting, (<http://www.ruudled.net/education/photopic2.php> 9/30/08)