



The CIE $V(\lambda)$ Function Isn't a
Photobiological Action Spectrum
– Is this Important?

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The basis of photometry is the spectral luminous efficiency function $V(\lambda)$

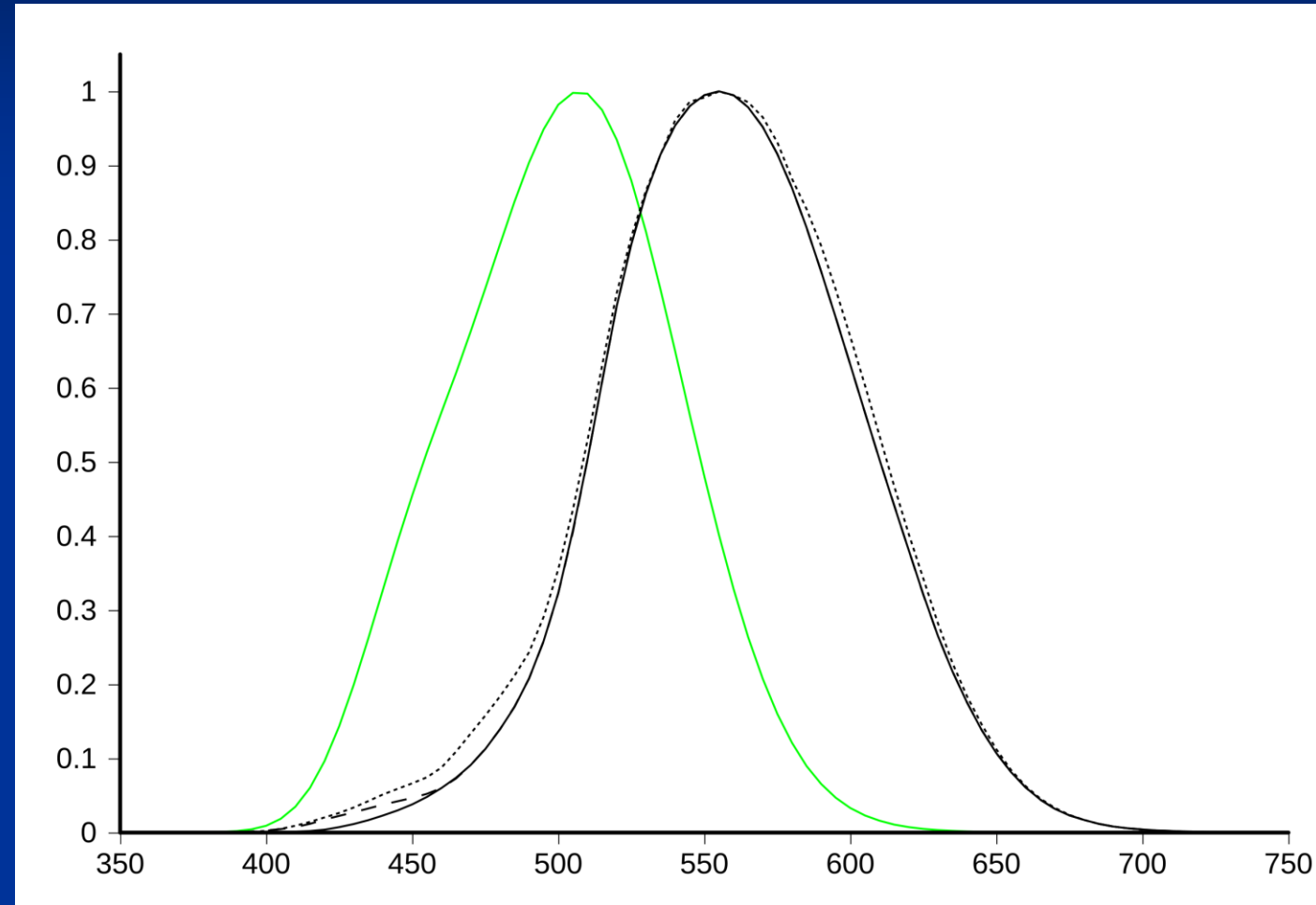
- The $V(\lambda)$ function was established in June 1924
- CIE held a “Birthday Celebration” this year at the BIPM in Sèvres (Paris) last June 3 – “a birthday of a mathematical function”
- A change in the values of $V(\lambda)$ at shorter wavelengths was proposed by several experts, including Prof. Andrew Stockman

What are the advantages/disadvantages:

- Greater accuracy for short-wavelength function weighting
- But, would not all photometer calibrations be affected
- Change in original emphasis on central visual acuity

Maybe we should examine the rationale

- The important fact that leads to the recommendation to revise the function is that it does not fully reflect the retinal sensitivity of the short-wave cone in the violet end of the spectrum.
- But greater uncertainty with age-related reduction in lens transmittance with age and variable macular pigment.



spectral luminous **efficiency**, <for a specified photometric condition>

$V(\lambda)$, <for [photopic vision](#)>; $V'(\lambda)$, <for [scotopic vision](#)>; $V_{\text{mes};m}(\lambda)$, <for [mesopic vision](#)>; $V_{10}(\lambda)$, <for the CIE 10° photopic photometric observer>; $V_M(\lambda)$, <for the CIE 1988 modified 2° spectral luminous efficiency function for [photopic vision](#)>

quotient of the [radiant flux](#) at [wavelength](#) λ_m and that at [wavelength](#) λ , such that both produce equally intense luminous sensations for a specified photometric condition and λ_m is chosen so that the maximum value of this quotient is equal to 1

Note 1 to entry: The spectral luminous efficiency of the human eye depends on a number of factors, particularly the state of visual [adaptation](#) and the size and position of the [source](#) in the [visual field](#). The photometric condition should be specified (e.g. photopic, scotopic, mesopic). If it is not specified, [photopic vision](#) is assumed and the symbol $V(\lambda)$ is used. The values of the $V(\lambda)$ function have been internationally agreed in 1924 by the CIE (Compte Rendu 6^e session, p.67), completed by interpolation and extrapolation (ISO 23539:2005(E)/CIE S 010/E:2004 Photometry – The CIE System of Physical Photometry), and recommended by the International Committee of Weights and Measures (CIPM) in 1972.

...and four other lengthy notes...

CIE ILV 17-21-090

luminous efficacy of radiation, <for a specified photometric condition>

K , <for [photopic vision](#)>; K' , <for [scotopic vision](#)>; $K_{mes,m}$, <for [mesopic vision](#)>; K_{10} , <for the CIE 10° photopic photometric observer>; K_M , <for the CIE 1988 modified 2° spectral luminous efficiency function for [photopic vision](#)>

quotient of [luminous flux](#) and the corresponding [radiant flux](#) for a specified photometric condition

Note 1 to entry: The photometric condition should be specified (e.g. photopic, scotopic, mesopic). If it is not specified, [photopic vision](#) is assumed and the symbol K is used. For other photometric conditions the respective symbol for identification shall be used.

Note 2 to entry: Luminous efficacy of radiation for [photopic vision](#) is expressed by

$$K = \frac{\Phi_v}{\Phi_e}$$

where Φ_v is [luminous flux](#) and Φ_e is [radiant flux](#).

Note 3 to entry: The value of the luminous efficacy of radiation for [photopic vision](#) for [monochromatic radiation](#) of frequency $\nu_{cd} = 540 \times 10^{12}$ Hz is defined as $683 \text{ lm} \cdot \text{W}^{-1}$ and denoted as K_{cd} . The

corresponding [wavelength](#), $\lambda_{cd} = n^{-1} \cdot c_0 \cdot \nu_{cd}^{-1}$ (where n is [refractive index](#) and c_0 is the speed of light in vacuum) in standard air, i.e. dry air at 15 °C and 101 325 Pa, containing 0,045 % of carbon dioxide by volume.....”

What was the rationale in 1924?

1. It is interesting that the framers of the original $V(\lambda)$ function appeared to be aware of this apparent discrepancy, but chose to weight what they saw as the dominance of the medium-wave and long-wave cones in the fovea centralis where visual acuity is greatest.
2. The fovea is almost devoid of short-wave sensitivity (“blue”) cones
3. The reasoning in 1924 may well have been the recognition that green and red wavelengths were sharply focused on the retina,
 1. Because of chromatic aberrations, indigo and violet wavelengths are focused in front of the retina thus reducing acuity (think of yellow marksman lenses!)
 2. SWCs therefore contribute little to (even detracting from) fine visual acuity.
 3. Lens fluorescence emission (at least outdoors) is in blue-violet – giving haze
4. They also wanted a smooth function that could be used to adjust the spectral sensitivity of a photodetector with then-existing glass filters!

NO. OF RODS OR CONES ($\times 10^3$)

140
120
100
80
60
40
20
0

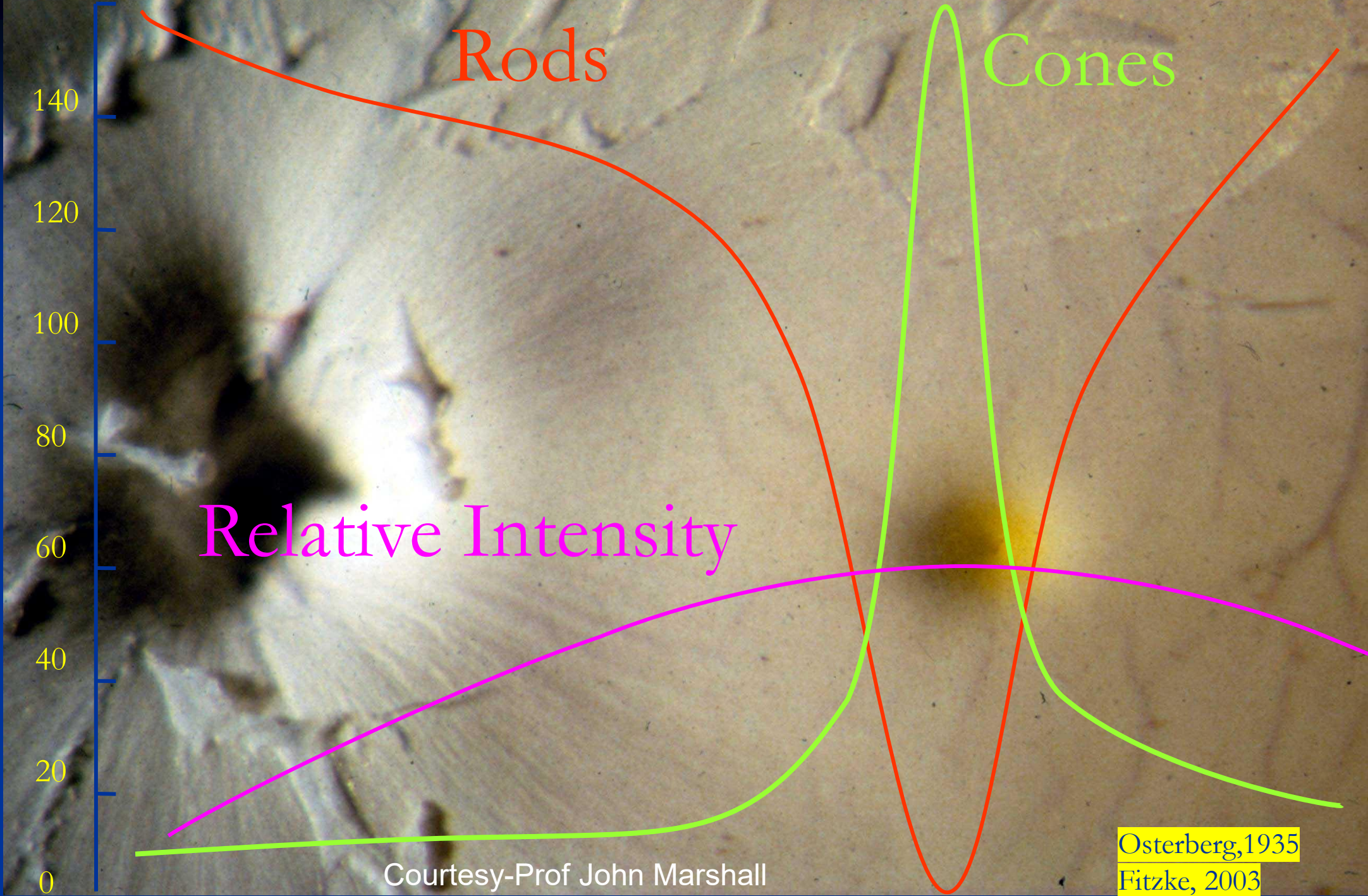
Rods

Cones

Relative Intensity

Courtesy-Prof John Marshall

Osterberg, 1935
Fitzke, 2003



Some possible aims in 1924?

- People read black and white printed pages. Color plates in books or journals were very rare and this was the case at least up through mid-century
- Color movies only appeared in mid-century
- Visual tasks for indoor lighting in schools and offices needed to be optimized for visual acuity and visual performance
- Color vision was apparently not a significant issue when it came to reading. Color TV only became common by 1960.

What about Selective Chromatic Adaptation?

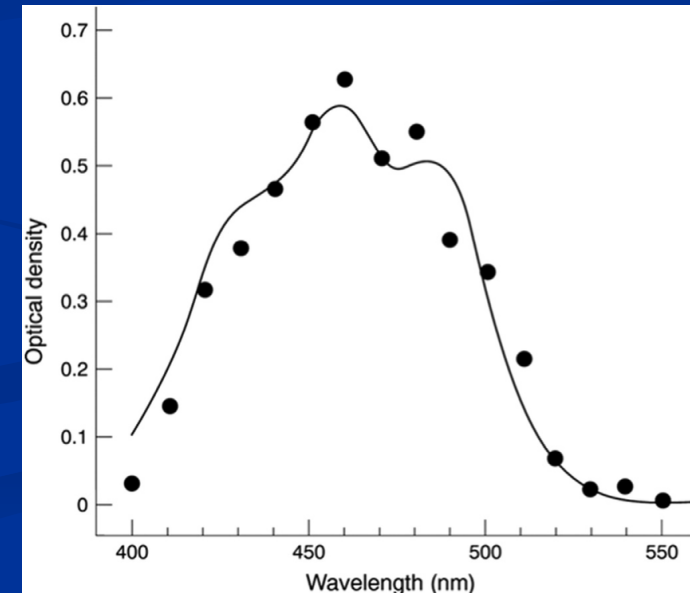
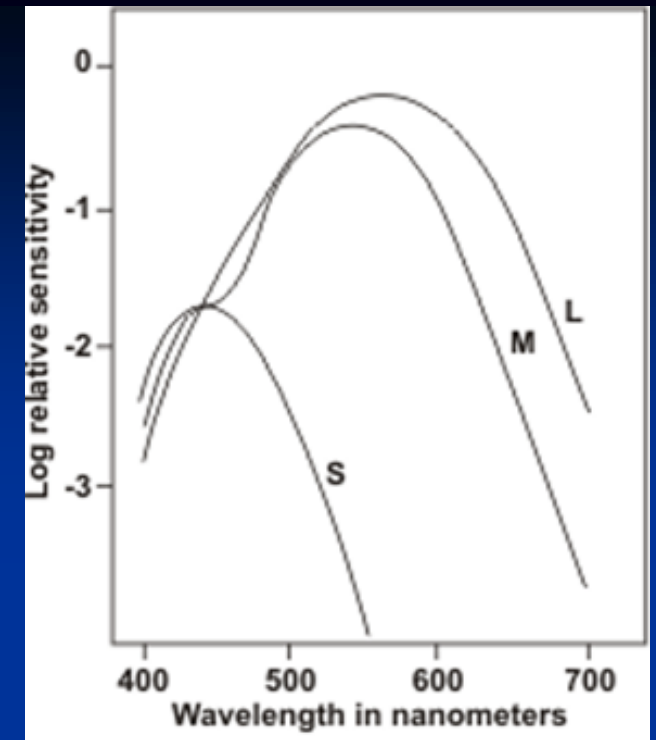
Selective Chromatic Adaptation adjusts the contributions of each type of cone depending on the available spectral luminance

This is apparent if you wear a strongly colored laser safety goggle, or “blue-blocker”, and after you remove it, you see the opposing color

Long recognized that SW Cones provide color and other information, but do not contribute to fine acuity; hence “shooters glasses”

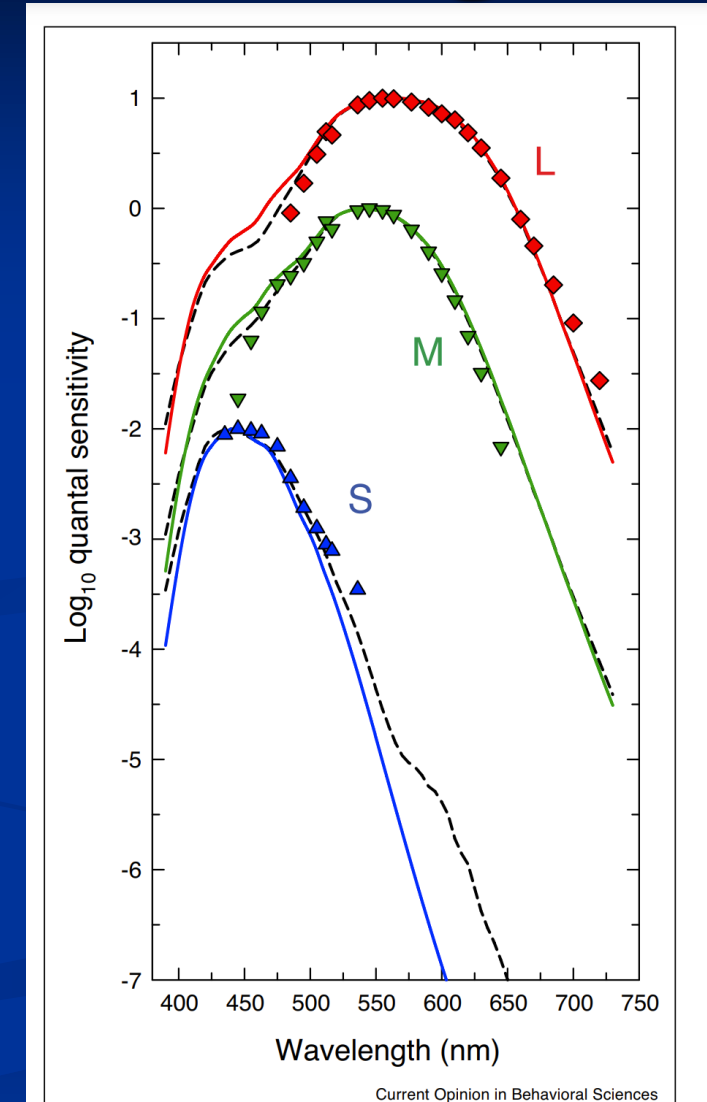


White appears “white” throughout the day although the solar spectrum changes throughout



The proposed change affects violet wavelengths

- The CIE has sanctioned the cone spectral sensitivity estimates of Stockman and Sharpe (Stockman and Sharpe, 2000, *Vision Res*) and their associated measures of luminous efficiency as “physiologically-relevant” standards for color vision (CIE, 2006; 2015).
- Do cone fundamentals require a change in the definition of $V(\lambda)$, the candela and the lumen? This is unclear to me? Why?



Current Opinion in Behavioral Sciences

Stockman (2005)

My Key Question:

Is the spectral luminous efficiency function for photopic vision, $V(\lambda)$,
A photobiological action spectrum?

Back to the CIE International Lighting Vocabulary – the ILV

17-21-036 CIE standard photometric observer

ideal observer having a relative spectral responsivity curve that conforms to the spectral luminous efficiency function for photopic vision, $V(\lambda)$, or to the function for scotopic vision, $V'(\lambda)$, and that complies with the summation law implied in the definition of luminous flux

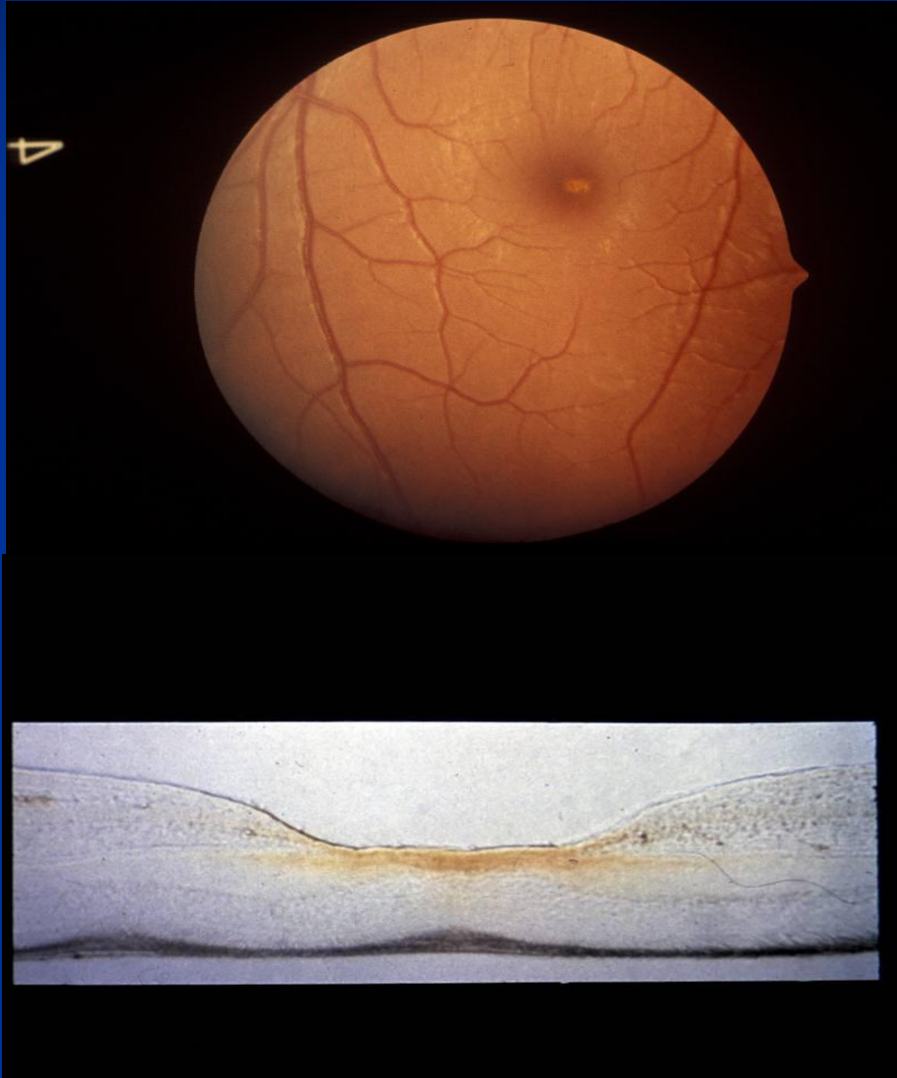
Note 1 to entry: See also ISO 23539:2005(E)/CIE S 010/E:2004 Photometry – The CIE System of Physical Photometry.

ANSWER: The $V(\lambda)$ function is an envelope weighting function of three different action spectra!

If not an action spectrum, what is $V(\lambda)$?

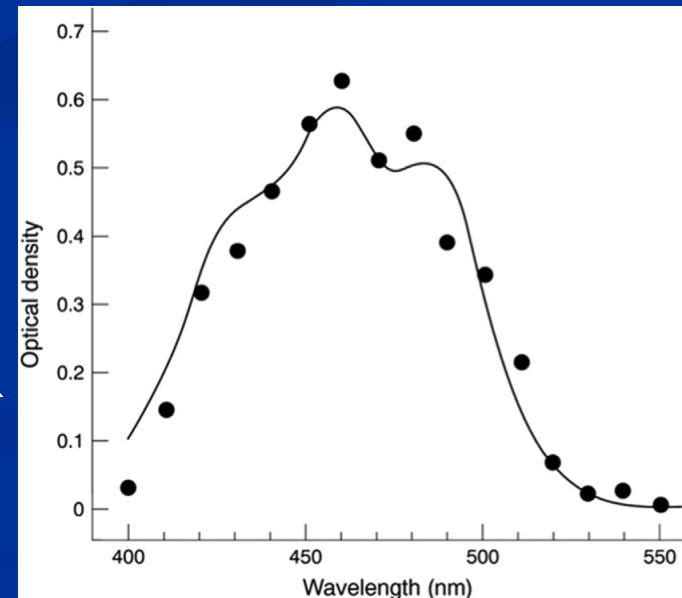
- It is an envelope spectral weighting function
- This is not unique, $S(\lambda)$ for the standard erythema function, and for the ultraviolet hazard functions relate to more than one chromophore.
- The ACGIH $S(\lambda)$ **ultraviolet hazard function** was derived as an envelope weighting function encompassing both photokeratitis and erythema action spectra to ease broad-band safety measurements.

Retinal Hazards: “the blue-light hazard” (or photic maculopathy) – Weighting Function $B(\lambda)$



- Action spectrum described by Ham, Mueller and Sliney, *Nature*, 1976
- Requires steady viewing for many seconds, as in retinal injuries from viewing a solar eclipse
 - Viewer has to overcome the natural aversion response to bright light

Macular Pigment
Spectral
Absorption



Conclusions

- We need to examine the real value of a stable $V(\lambda)$ function
- If color science demands a better $V(\lambda)$ function can we not just add a new $V_p(\lambda)$ to the century-old CIE $V(\lambda)$ function – just like we now have: $V_m(\lambda)$, $V_{10}(\lambda)$? or $V'(\lambda)$?
- Would the change add more than a few percent efficacy to high CCT LEDs?
- In my study of this, I would conclude that we add a new $V(\lambda)$ function.
- Perhaps $V_S(\lambda)$ for Andrew Stockman?