**Input paper:** ENG19-3.1.1.1

**Input paper for the following Committee(s):** **Purpose of paper:**

(Select as appropriate)

ARM  ENG  PAP  Input

ENAV VTS  Information

**Agenda item** n.n

**Technical domain/ Task number** …………………………………

**Author(s)/Submitter(s)** ……Alwyn Williams…………

Review of Cone Fundamentals and Its Effect on Calcualted Intensity of Measured Lights

# Summary

On 3rd June 2024, a workshop to celebrate the 100-year anniversary of the adoption of was held by the International Commission on Illumination (CIE) and Consultative Committee for Photometry and Radiometry (CCPR). Held at the BIPM, Paris, France, it gave an opportunity for the attendees to review the history of the function and get an understanding of the fundamental change that might happen in the relatively near future.

It is proposed that the fundamental colour matching functions used in photometry and colorimetry would be modified to align with the results of relatively recent experiments. The change is often called “cone fundamentals” because the functions are said to more accurately match how the human visual system operates in practice.

The change is not without controversy, and CIE are putting together a research group to investigate the impact of such a change on the industry. It was said that the earliest time that the research group would report back is five years, meaning that there is no immediate change expected. Even then, it is expected that the change to cone fundamentals will be a gradual one.

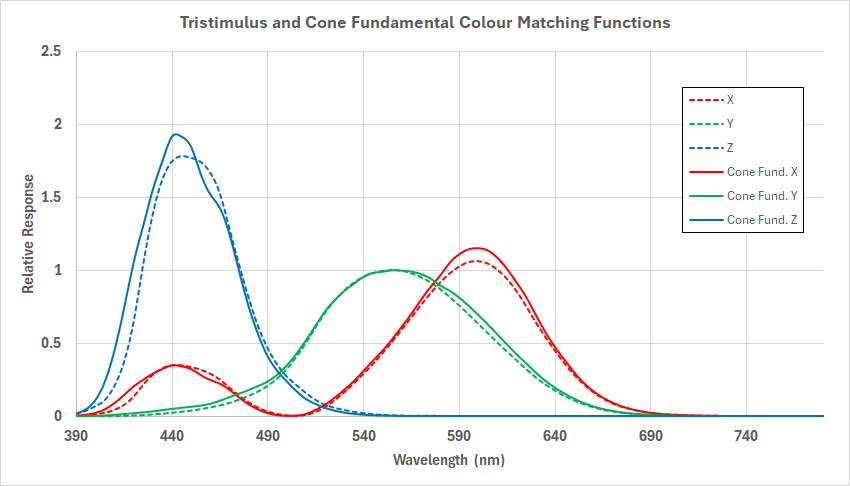
This paper is a briefing to IALA members on the possible future of photometry, and to quantify some changes that could be seen after the changes are implemented.

# Cone Fundamentals

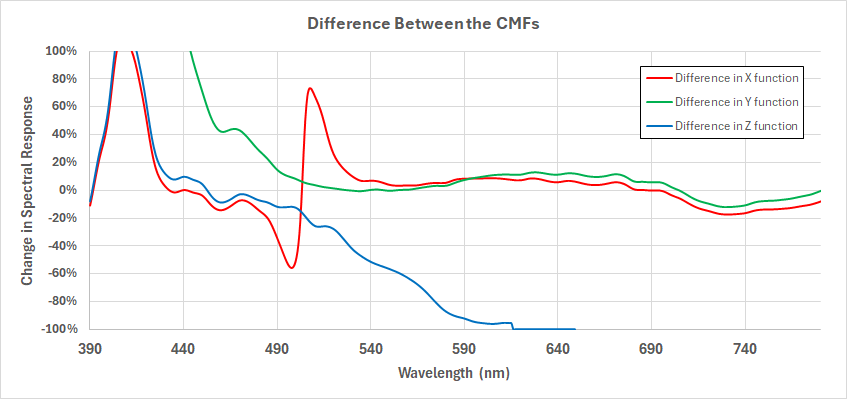
Photometry and colorimetry rely on a set of functions known as the colour matching functions (CMFs). These functions are derived from experiments that attempt to quantify the spectral response of the human visual system. There are three functions which broadly relate to the three types of photoreceptor cells in the human eye known as cones. The functions commonly referred to as , and , and are well defined by CIE for the wavelength range of 380 to 780 nm [1]. The functions have been deduced such that the function is the same as the spectral luminous efficiency function used to define the terms in photometry.

There are two sets of functions for different types of observations: the 2-degree and 10-degree observer. For the purposes of this paper, we shall focus on the 2-degree observer as this is applicable for viewing marine AtoN lights. However, the principles also apply to 10-degree observer.

Since 2006, CIE have published a revised set of CMFs that are derived from “cone fundamentals” experiments [2], [3]. Figure 1 shows the existing and cone fundamentals CMFs for comparison, with Figure 2 quantifying the differences relative to the existing CMF. It should be noted that CMF derived from cone fundamentals are not defined below 390 nm, and the analysis is truncated at 780 nm to enable direct comparison with the existing CMFs.



1. Existing tristimulus CMFs (dotted line), and the tristimulus CMFs based on cone fundamentals (solid line).



1. Difference between the existing and cone fundamental CMFs

As can be seen from the two figures, there are significant differences between the two sets of CMFs, most notably in the shorter wavelengths. In these areas, the eye response is found to be more sensitive to those wavelengths than the original CMFs accounted for. Indeed, at some shorter wavelengths, the new function implies an increase in responsivity by a factor of about seven times.[[1]](#footnote-2)

The switch to cone fundamentals would affect both colorimetry, because the CMF have changed, and photometry, because will change to match the function of the new cone fundamentals CMFs.

In this paper, we shall not consider the implications on colour measurements. This needs further work and understanding, especially in defining the colour boundaries that IALA uses to determine the suitability of light colour for their signalling system. In any case, and as always, IALA should take the lead from CIE on this matter if any changes are made.

# Effect on Photometry Measurements

Over the years, GRAD have built up a considerable database of spectroradiometric measurements of lights tested at their facility, and this was used to understand the impact of the change to cone fundamentals on the calculated luminous intensity. In order to get a broad overview of the different LED light sources used in marine lanterns, the author focussed on using data for sector lights. Some single-colour lanterns and bare light sources were used to increase the number of samples in the white and red colours as these seem to be the most popular colours in our database.

During the comparison, the spectrum of the light was used to calculate the intensity of the light with the existing function, and a second intensity was calculated using the cone fundamentals function as the weighting function. The results are shown in Table 1.

1. Relative differences between intensities calculated using existing V(λ) and the equivalent using cone fundamentals.

|  |  |  |  |
| --- | --- | --- | --- |
| Light Colour | Sample Size | Difference | |
| Mean | S.D. |
| **White** | 21 | +4.8 % | 0.160 % |
| **Red** | 16 | +11.3 % | 0.070 % |
| **Green A** | 4 | +5.2 % | 0.198 % |
| **Green B** | 4 | +1.5 % | 0.138 % |
| **Yellow** | 1 | +7.3 % | - |
| **Blue** | 1 | +36.1 % | - |
| **Total** | **38** |  |  |

The results show some interesting trends. It seems that regardless of colour, there is an increase in the calculated intensity. There is also little variation between different lights of the same colour, as shown in the standard deviation column. This is a little surprising for the white colour since there can be quite a variation in the spectra of white lights, depending on the correlated colour temperature (CCT) of the white light used in the lantern.

The biggest changes appear to be for blue lights. This is not surprising given that, as mentioned earlier, there has been a substantial increase in the response at the shorter wavelengths. Nevertheless, an increase of about 36 % in the intensity is considerable if the single sample used is representative of typical blue LED-based lights used in the industry.

Similarly, red lights have an increase of about 11 % in intensity after the change to cone fundamentals.

# Discussion

The results shown in the previous section are certainly very interesting and point to how colorimetry and photometry can change with a shift from the existing CMFs to those based on cone fundamentals.

One should be careful in interpreting these results. This does not mean that lights are suddenly brighter, but rather the intensities ascribed to a particular “brightness” has a higher value. Does this matter? At the time of writing, the answer is unclear, and its implications needs to be carefully thought through.

The research group within CIE are exploring the ramifications of changing the CMF and function, including how changes in the intensity value should be handled [4]. They are also considering the practical implications such as needing to replace all photometers so that their spectral response matches the new function. It could be a very costly exercise for laboratories that use such devices, either in financial terms or in measurement effort terms where a spectral correction factor would need to be determined on a per-measurement basis.

If CIE formally adopts the cone fundamentals as the basis for future colorimetry and photometry, then IALA should follow suit. The colour boundaries for acceptable light colour will almost certainly need to change to reflect the new CMF. It should be noted that does not necessarily mean that lights currently compliant with the colour boundaries will end up not being compliant (or vice versa).

Finally, it should be noted that it is entirely possible that CIE will decide not to formally adopt the cone fundamentals as the basis for the CMF and functions, in which case, no action would be required by IALA or its members.

# References

[1] CIE TC 1-85, ‘CIE 015:2018 Colorimetry, 4th Edition’, International Commission on Illumination (CIE), Vienna, Austria, 2018. doi: 10.25039/TR.015.2018.

[2] CIE TC 1-36, ‘CIE 170-1:2006 Fundamental Chromaticity Diagram with Physiological Axes – Part 1’, CIE, Vienna, Austria, Technical Report, 2006. doi: 10.25039/tr.170-1.2006.

[3] A. Stockman, ‘Cone fundamentals and CIE standards’, *Vis. Percept.*, vol. 30, pp. 87–93, Dec. 2019, doi: 10.1016/j.cobeha.2019.06.005.

[4] CIE, ‘Implementation of CIE 2006 Cone Fundamentals in Photometric and Colorimetric Measurements’. Accessed: Aug. 06, 2024. [Online]. Available: https://cie.co.at/researchforum/rf-05

# Action requested of the Committee

The Committee is requested to take note of developments at CIE on this matter and be aware of how the changes may affect light measurements by IALA members.

1. As a side note, there was evidence of this in the original set of experiments carried out, but for reasons unknown, these were ignored for a set of experiments that had much lower responsivity at the short wavelengths. Had the alternative set of data been adopted, the difference caused by the adoption of cone fundamentals would have been much smaller today. [↑](#footnote-ref-2)