User Guide to the $\alpha$-opic Toolbox for implementing CIE S 026


© CIE 2020 - All rights reserved
The α-opic Toolbox and User Guide were designed by the International Commission on Illumination (CIE) to enable calculations and conversions of quantities related to ipRGC-influenced responses to light (IIL responses, or non-visual effects of light), following the international standard CIE S 026:2018. System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light. CIE, Vienna (DOI: 10.25039/S026.2018).

The α-opic Toolbox is a CIE publication (DOI: 10.25039/S026.2018.TB) under the Division 6 Reportership DR 6-45 Publication and maintenance of the CIE S 026 Toolbox. The α-opic Toolbox supports the usage of CIE S 026, but is not part of the official international standard. The toolbox was designed with feedback from experts including the participants of the Tutorial on CIE S 026. Use and application of the new metrology for ipRGC-influenced responses to light, 14-15 March 2019, Eindhoven.

No liability is taken by CIE for any potential errors due to calculations with the α-opic Toolbox. It is recommended that users check the results against manual calculations. Considered feedback is welcome and should be sent to the Reporter of DR 6-45 via ciecb@cie.co.at who will aim to answer any questions as quickly as possible.
Toolbox – Author and advisors

• The following member of DR 6-45 took part in the preparation of the Toolbox and this User Guide
  – Price, L.L.A. Public Health England, United Kingdom

• The following experts acted as advisors:
  – Peirson, S.N. University of Oxford, United Kingdom
  – Schlangen, L.J.M. Eindhoven University of Technology, The Netherlands
  – Spitschan, M. University of Oxford, United Kingdom
  – Lang, D. LEDVANCE, Munich, Germany
  – Blattner, P. METAS, Bern, Switzerland
Toolbox – Main features

• Selection of spectral data used for calculations
  Built-in illuminants A, D65, E, FL11, and LED-B3 (all: range 380 nm to 780 nm, step 1 nm) (CIE, 2018a); or User-defined spectral data with a choice of wavelength step (1 nm, 2 nm, 4 nm or 5 nm)

• Choice of basic quantity
  Photon radiance, photon irradiance, radiance, irradiance, luminance, illuminance (CIE, 2011; BIPM, 2019)
  Control of SI prefixes, e.g. m in mW·m²·sr⁻¹, μ and c in μW·cm², k in klx, c in cd·cm²

• CIE S 026 calculations and conversions (CIE, 2018b)
  Basic quantity and additional α-opic output quantities are calculated: α-opic irradiance, α-opic equivalent daylight (D65) illuminance (α-opic EDI), α-opic photon irradiance, or their radiance and luminance analogues, as well as the α-opic efficacy of luminous radiation (α-opic ELR)
Toolbox – Additional features

• Charts and action spectra
  The test spectrum and the reference spectrum (default = D65) before and after $\alpha$-opic action spectra weighting

• Glossary
  List of quantities, abbreviations and symbols from CIE S 026 (CIE, 2018b)

• Advanced outputs
  Switch outputs between the quantities from CIE S 026 and the former Lucas et al., 2014 recommendations
  Displays values for the reference source, matched to the test source inputs
  Displays $\alpha$-opic Daylight Efficacy Ratio ($\alpha$-opic DER)
  Control of SI prefixes
Toolbox – Orientation

Inputs sheet

Outputs

Charts

CIE S 026 α-opic Toolbox

Instructions + warnings

Dark blue = data entry

* = Errors

CIE S 026 α-opic Toolbox

Outputs

- Enter a title for your data
- Scaling factor for inputs

- Irradiance, W/m²
- Illuminance, lx
- Log photosynthetic irradiance, µmol/m²s

- a-opic Irradiance, W/m²
- a-opic Irradiance / spectral Irradiance / a-opic action spectrum / δi

- a-opic efficacy of luminous radiation, entr.in. -1

- a-opic Eff / a-opic Irradiance / Illuminance

- a-opic equivalent daylight (06) Irradiance, lx

- a-opic EL / a-opic Irradiance / a-opic EL for daylight (06)

Charts

- CIE S 026 α-opic Toolbox

Glossary

- CIE S 026 α-opic Toolbox – v1.040 - 2020/02

Action spectra

Advanced Outputs

see page 24
Example for built-in spectra

First enter a title

< Quick calculation >

1. Select from list
(5 CIE illuminants) < LED-B3 >

2. Select quantity
(6 options) < illuminance >
and units
(SI prefixes) < k > < blank >

3. Enter value
(0.10 klx = 100 lx) < 0.10 >

Finally clear unused inputs
(i.e. manually clear cells C24:C424)

All of A, D65, E, FL11, LED-B3 have a range 380 nm to 780 nm, and step 1 nm
Inputs – Dealing with Error Messages

- Check whether there is red text under ‘Error messages’.
- In case of (red) error messages, follow instructions relating to the input/cell (usually highlighted with a red asterisk).
- If not, please go to the next page of the User Guide (Output Results).

NOTE Use a comma or a dot as your decimal separator based on your Excel settings.
Basic quantities
irradiance, illuminance and log photon irradiance

α-opic irradiance
(in W·m⁻²)

α-opic ELR
efficacy of luminous radiation, (in mW·lm⁻¹)

α-opic EDI
equivalent daylight (D65) illuminance, (in lx)

α-opic photon irradiance
(in s⁻¹·m⁻²)
Each value is presented as the logarithm to base 10 (log₁₀) of the α-opic photon irradiance, Q, divided by 1 s⁻¹·m⁻² (log₁₀ can also be written lg).
irradiance
(in W·m⁻²)

illuminance
(in lx)

photon irradiance
(in s⁻¹·m⁻² and presented as a logarithm)
Outputs – α-opic irradiance

\[ E_\alpha \text{ (in } \text{W} \cdot \text{m}^{-2}\text{)} \]

"effective photobiological irradiance with the spectral irradiance, \( E_{e,\lambda}(\lambda) \), spectrally weighted with the α-opic action spectrum \( s_\alpha(\lambda) \)"
Example calculation – Melanopic irradiance

\[ \sum \text{spectral irradiance} \times \text{melanopic action spectrum} = 83.9 \text{ mW} \cdot \text{m}^{-2}, \text{ or } 0.08 \text{ W} \cdot \text{m}^{-2}, \text{ as shown on p. 11} \]
Outputs – α-opic ELR

ELR = Efficacy of Luminous Radiation

\[ K_{\alpha,v} = \frac{E_{\alpha}}{E_v} \]

\[ \text{ELR} = \frac{E_v}{E_{\alpha}} \]
EDI = Equivalent Daylight (D65) Illuminance

"illuminance, produced by radiation conforming to standard daylight (D65), that provides an equal α-opic irradiance as the test source"
Outputs – $\alpha$-opic EDI calculation method

EDI = Equivalent Daylight (D65) Illuminance

"illuminance, produced by radiation conforming to standard daylight (D65), that provides an equal $\alpha$-opic irradiance as the test source"

\[
E_{v,\alpha}^{D65} = \frac{E_{\alpha}}{K_{\alpha,v}^{D65}}
\]

since \( K_{\alpha,v} = \frac{E_{\alpha}}{E_v} \)

\( K_{\alpha,v}^{D65} \) are five fixed values

<table>
<thead>
<tr>
<th>$\alpha$-opic</th>
<th>$S$-cone-opic</th>
<th>M-cone-opic</th>
<th>L-cone-opic</th>
<th>Rhodopic</th>
<th>Melanopic</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{v,\alpha}^{D65}$</td>
<td>61.88 mW.lm⁻¹</td>
<td>88.40 mW.lm⁻¹</td>
<td>99.78 mW.lm⁻¹</td>
<td>69.85 mW.lm⁻¹</td>
<td>63.24 mW.lm⁻¹</td>
</tr>
</tbody>
</table>
Example calculation – Melanopic equivalent daylight (D65) illuminance

\[
\sum \text{spectral irradiance, } \text{mW/m}^2/\text{nm} \times \frac{1}{K_{D65,\text{mel,v}}} = \text{melanopic EDI}
\]

\[
\sum \frac{1}{1.326} = 63.2 \text{ lux}
\]

as shown on p. 15

= melanopic EDI
Example calculations – Summary

\[
\text{melanopic irradiance} \div \text{melanopic ELR} = \text{melanopic EDI}
\]

\[
\frac{83.9 \text{ mW} \cdot \text{m}^{-2}}{1.326 \text{ mW} \cdot \text{lm}^{-1}} = 63.2 \text{ lx}
\]
Outputs – \( \alpha \)-opic photon irradiance

\[ E_{p,\alpha} \text{ (in } s^{-1} \cdot m^{-2}) \]

"effective photobiological photon irradiance with the spectral photon irradiance, \( E_{p,\lambda}(\lambda) \) (or number of photons per second per square metre), spectrally weighted with the \( \alpha \)-opic action spectrum \( s_{p,\alpha}(\lambda) \)"

Each value is presented as the logarithm to base 10 (\( \log_{10} \)) of the \( \alpha \)-opic photon irradiance, \( Q \), divided by \( 1 s^{-1} \cdot m^{-2} \).
**Photon irradiance in standard notation**

\[(\text{unweighted}) \text{ irradiance} = \int \text{spectral irradiance} \cdot d\lambda\]
\[(\text{photopic}) \text{ illuminance} = K_m \cdot \int \text{spectral irradiance} \cdot V(\lambda) \cdot d\lambda, \text{ where } K_m \approx 683 \text{ lm} \cdot \text{W}^{-1}\]
\[(\text{unweighted}) \text{ photon irradiance} = \int \text{spectral photon irradiance} \cdot d\lambda\]

<table>
<thead>
<tr>
<th>irradiance, W.m⁻²</th>
<th>illuminance, lx</th>
<th>log photon irradiance/(s⁻¹.m⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.32</td>
<td>100.00</td>
<td>17.953</td>
</tr>
</tbody>
</table>

**log α-opic photon irradiance, log Q/(s⁻¹.m⁻²), where**

\[\alpha\text{-opic photon irradiance} = \int \text{spectral photon irradiance} \cdot \text{photon system } \alpha\text{-opic action spectrum} \cdot d\lambda\]

<table>
<thead>
<tr>
<th>S-cone-opic</th>
<th>M-cone-opic</th>
<th>L-cone-opic</th>
<th>Rhodopic</th>
<th>Melanopic</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.057</td>
<td>17.544</td>
<td>17.666</td>
<td>17.411</td>
<td>17.315</td>
</tr>
</tbody>
</table>

**α-opic photon irradiance in standard notation**

\[\text{e.g. } 2.065\times10^{17} = 10^{17.315}, \text{ with rounding to 3 decimal places}\]

<table>
<thead>
<tr>
<th>α-opic photon irradiance, s⁻¹.m⁻²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.139×10¹⁷</td>
</tr>
<tr>
<td>3.503×10¹⁷</td>
</tr>
<tr>
<td>4.638×10¹⁷</td>
</tr>
<tr>
<td>2.578×10¹⁷</td>
</tr>
<tr>
<td>2.065×10¹⁷</td>
</tr>
</tbody>
</table>
Example for user spectra

1. Select ‘User’ from list
   < User >

2. Select spectral quantity and units
   (4 options*)  < irradiances >
   (SI prefixes)  < μ > < c >

* Luminance and illuminance are not supported as spectral inputs
2. Select spectral quantity (4 options) \(<\text{irradiance}>\) and units (SI prefixes) \(<\mu> <\text{c}>\)

3. Clear this input

4. Enter resolution (1 nm, 2 nm, 4 nm or 5 nm) \(<2>\)

5. Enter spectral data (380 nm to 780 nm)

Finally clear any data below the row for 780 nm.

The spectral quantity, units and the resolution of the spectral data in step 5 depend on steps 2 and 4, as indicated by the arrows.
Charts – Spectra and $\alpha$-opic weightings

Test = The selected input spectrum

Test = The selected input spectrum

Ref. = The reference spectrum

Ref. = The reference spectrum

D65, Reference source: illuminance = 0.1 klx

D65, Reference source: illuminance = 0.1 klx

The input data is called the Test source. The default CIE S026 Reference source is daylight (D65); Lucas et al., 2014 uses equi-energy (E).
The units used on the y-axis depend on the prefixes selected in inputs cells C12 and C13. The units used in the chart titles depend on the prefixes selected in Advanced Outputs cells H10 and H11.
Glossary (see References, page 29, for further information)

List of quantities, abbreviations and symbols

Previously published (CIE DIS 017:2016; CIE 018:2019)

\( E_v = \) (photopic) illuminance; \( L_v = \) (photopic) luminance

\( E = E_e = \) irradiance \((i.e. \text{ unweighted})\); \( L = L_e = \) radiance \((i.e. \text{ unweighted})\)

\( E_p = \) photon irradiance \((i.e. \text{ unweighted})\); \( L_p = \) photon radiance \((i.e. \text{ unweighted})\)

From CIE S 026:2018

\( \alpha \)-opic \((\alpha)\) may represent any one of S-cone-opic \((\text{sc})\), M-cone-opic \((\text{mc})\), L-cone-opic \((\text{lc})\), rhodopic \((\text{rh})\) and melanopic \((\text{mel})\)

\( s_{\alpha}(\lambda) = s_{e,\alpha}(\lambda) = \alpha \)-opic spectral weighting function \((\text{action spectrum})\)

\( K_{\alpha,v} = \alpha \)-opic efficacy of luminous radiation, \textbf{\( \alpha \)-opic ELR}  
\( K_{\text{D65},\alpha,v} = \alpha \)-opic ELR for daylight \((\text{D65})\)  
\( \gamma_{\text{D65},\alpha,v} = \alpha \)-opic daylight \((\text{D65})\) efficacy ratio, \textbf{\( \alpha \)-opic DER}  

\( E_{\alpha} = E_{\alpha,e} = \alpha \)-opic irradiance \((i.e. \text{ weighted by } s_{\alpha}(\lambda))\)  
\( E_{\text{D65},\alpha,e} = \alpha \)-opic equivalent daylight \((\text{D65})\) illuminance, \textbf{\( \alpha \)-opic EDI}  

\( L_{\alpha} = L_{\alpha,e} = \alpha \)-opic radiance \((i.e. \text{ weighted by } s_{\alpha}(\lambda))\)  
\( L_{\text{D65},\alpha,e} = \alpha \)-opic equivalent daylight \((\text{D65})\) luminance, \textbf{\( \alpha \)-opic EDL}  

From CIE S 026:2018 and 9th edition of SI Brochure

\( s_{p,\alpha}(\lambda) = \alpha \)-opic spectral weighting function \((\text{action spectrum})\) in the photon system \((\text{renormalised to maximum of 1})\)  
\( E_{p,\alpha} = \alpha \)-opic photon irradiance \((i.e. \text{ weighted by } s_{p,\alpha}(\lambda))\)  
\( L_{p,\alpha} = \alpha \)-opic photon radiance \((i.e. \text{ weighted by } s_{p,\alpha}(\lambda))\)

Further \( \alpha \)-opic quantities and their symbols can be derived, e.g. \( \alpha \)-opic equivalent daylight \((\text{D65})\) luminous flux, \( \Phi_{\text{D65},\alpha} \).

However, any other abbreviations, e.g. "\( \alpha \)-opic EDLF" may be ambiguous, and should be avoided.

Due to prior publications, the subscript order for ELR and DER differs from \( \alpha \)-opic equivalent daylight \((\text{D65})\) quantities.
Advanced Outputs – Output mode selection

"Lucas et al., 2014" mode
Provided for checking old calculations only

Reverts to non-standard terminology
Advanced Outputs – Daylight efficacy ratio (DER)

"α-opic daylight (D65) efficacy ratio, <for a source>"

\[ \gamma_{\alpha, \nu}^{D65} = \frac{K_{\alpha, \nu}^{D65}}{K_{\alpha, \nu}^{D65}} \]

where \( \gamma_{\alpha, \nu}^{D65} \) converts illuminance, \( E_{\nu}^{D65} \), to α-opic EDI:

\[ E_{\nu, \alpha}^{D65} = E_{\nu}^{D65} \cdot \gamma_{\alpha, \nu}^{D65} \]
Advanced Outputs – Reference source values

Reference source values are shown matched to the input for the test source

Reference source (automatic) = Daylight (D65) for CIE S 026 mode
Equi-energy (E) for Lucas et al., 2014 mode
The user can choose the output prefixes that determine the units used in the output fields below.

**Area prefixes are OK for luminance, e.g. cd.mm$^{-2}$, but are not a valid option for illuminance, lx.**
1. The α-opic Toolbox is deliberately designed without macros or range names, meaning that it can be integrated with other spreadsheets (including your own macros if you should wish).

2. So if you have trouble pasting spectral data into Inputs (reported on some platforms), try adding a blank sheet for pasting and link the Inputs to the cells containing your data on this new sheet.

3. Excel expects you to enter numerical data using the regional number format settings on your system. This applies to how you write numbers with decimals, for example “0,1” vs “0.1”.

4. Unused cells should be cleared of all contents, including those in the spectral data (Inputs, cells C24:C424). The error messages in red text should alert you to when this has not been completed.

5. The SI prefix dropdown boxes temporarily interpret “m” as “M”. However, provided you choose the option you want, this has no further impact, and the calculations will always match the case of the prefix as shown on the Inputs sheet (and Advanced Output sheet) after entry.

6. The Chart titles’ units are linked to cells H10:H11 of the Advanced Outputs sheet; the y-axis and the Chart y-axes’ units are linked to cells C12:C13 of the Inputs sheet.

7. Always subject your calculations to sense-checking and manual spot-checking, based on the data and definitions in CIE S 026:2018. Please avoid re-using a user-modified Toolbox (see 1.-2. above).
References


