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Mesopic Photometry for SSL

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Metrology for SSL Meeting

24th April 2013

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Outline

- Brief overview of CIE system for mesopic photometry
- Relevance of mesopic photometry for SSL
- Is mesopic photometry all that matters?
- How to calculate values for mesopic quantities
- Issues associated with implementation of mesopic photometry
  - Current status of work in the CIE
- Use of quantities and units in mesopic photometry
- Next steps

Metrology for Solid State Lighting

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Eye sensitivity and light level

Photopic Vision

- Illuminance levels > 50 lux
- Spectral response of the eye independent of illumination level
- Visual process governed by cone receptors
- Basis for trichromatic colour vision
- Eye is in a stable state

Mesopic Vision

- Illuminance levels between ~ 50 lux and 0.05 lux
- Visual process dependent on the level of illumination
- Eye is NOT in a stable state

Scotopic Vision

- Illuminance levels <0.05 lux down to 3 μlux
- Visual process governed by rod receptors
- No colour perception
- Eye is in a stable state

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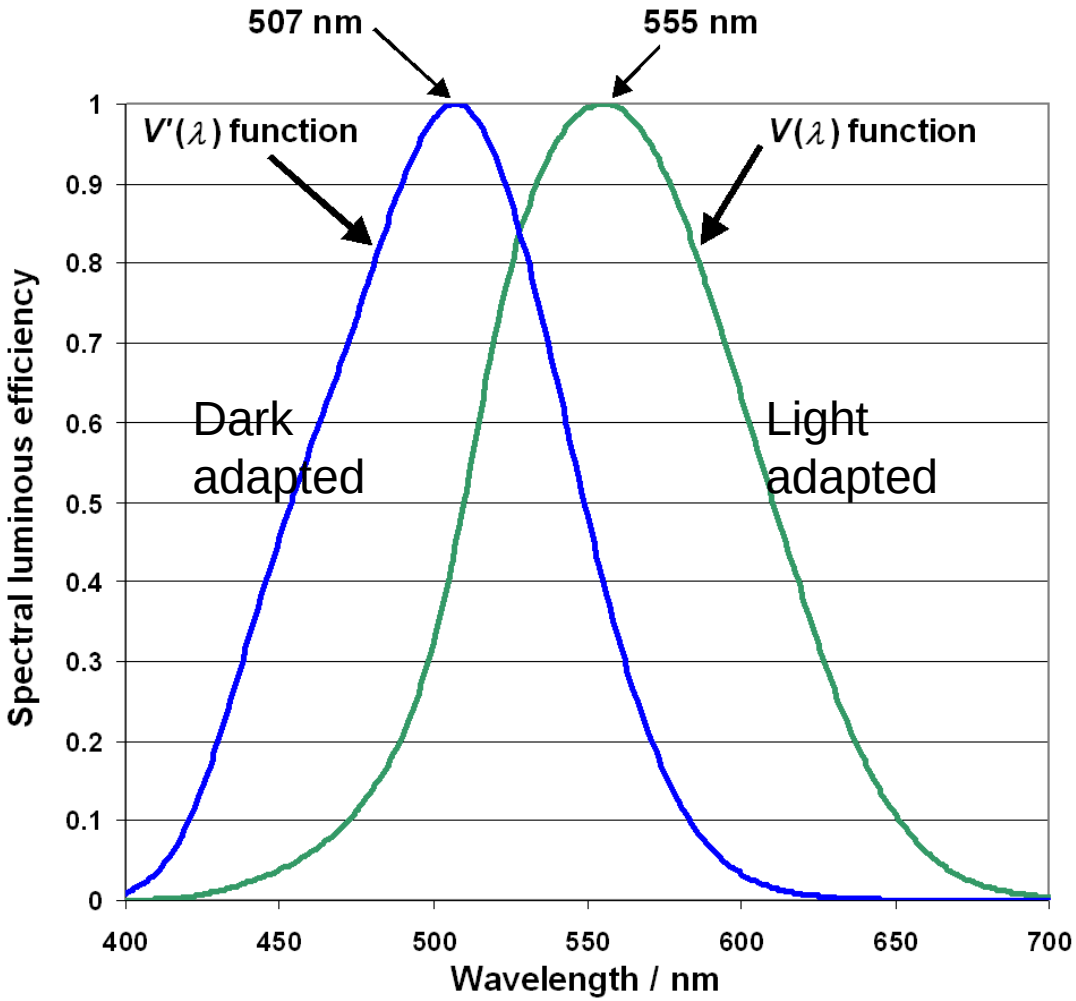
Standard observer functions



Photopic and scotopic standard observer functions are foundations of system for physical photometry

$$Q_v = 683 \int Q_e(\lambda) V(\lambda)\, d\lambda$$

$$Q_v' = 1700 \int Q_e(\lambda) V'(\lambda)\, d\lambda$$

What spectral luminous efficiency function to use in mesopic region?

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CIE 191: System for mesopic photometry

- Bridges the gap between the CIE photopic and scotopic standard photometric observer functions
- Defines the spectral luminous efficiency functions to be used in the mesopic region
- Provides a system for precise determination of photometric quantities for all types of luminous source at all levels

$$V_{\text{mes}}(\lambda, m) = \frac{1}{M(m)}\{mV(\lambda) + (1-m)V'(\lambda)\}$$

Normalising factor such that maximum value of $V_{\text{mes}}(\lambda)$ is unity

if $L_{\text{mes}} \geq 5.0$ cd·m^{-2}, then $m = 1$
if $L_{\text{mes}} \leq 0.005$ cd·m^{-2}, then $m = 0$

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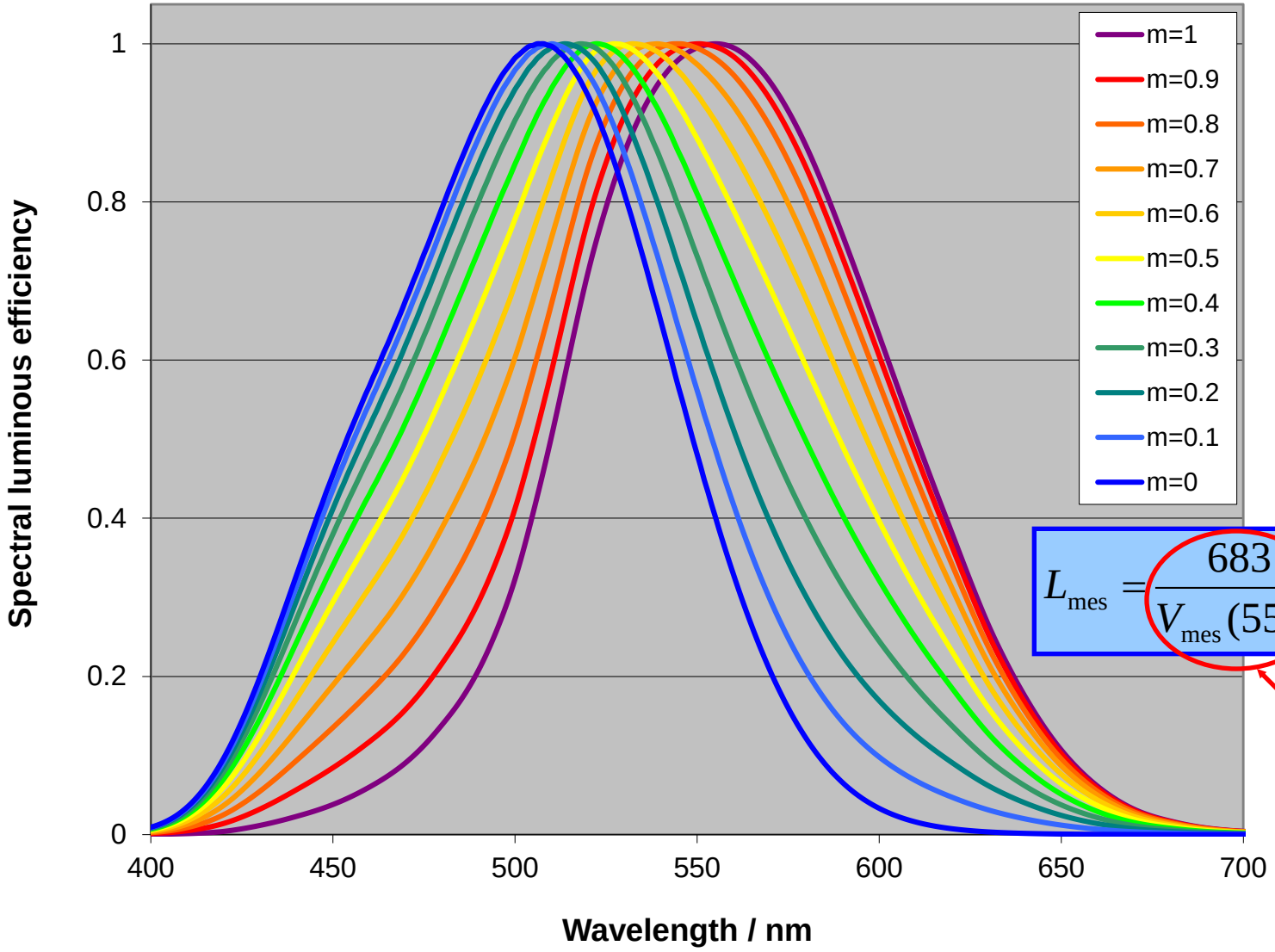
Spectral luminous efficiency functions

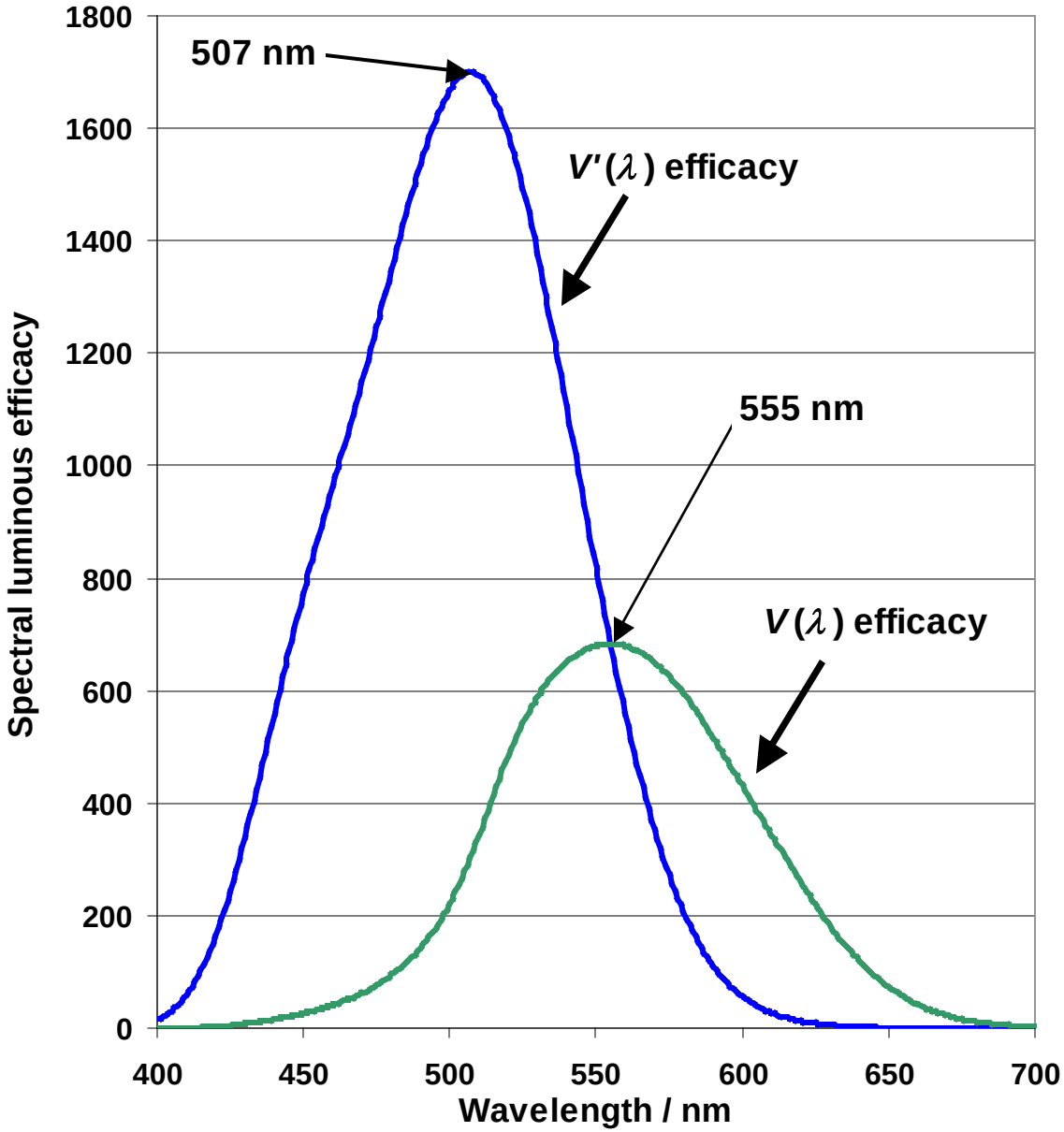


$$L_{\text{mes}} = \frac{683}{V_{\text{mes}}(555)} \int L_{\text{e}}(\lambda) V_{\text{mes}}(\lambda) \mathrm{d}\lambda$$

Maximum spectral luminous efficacy

Spectral luminous efficacy

In accordance with SI definition of candela, luminous efficacy at 555 nm is **always** 683 lm W^{-1}



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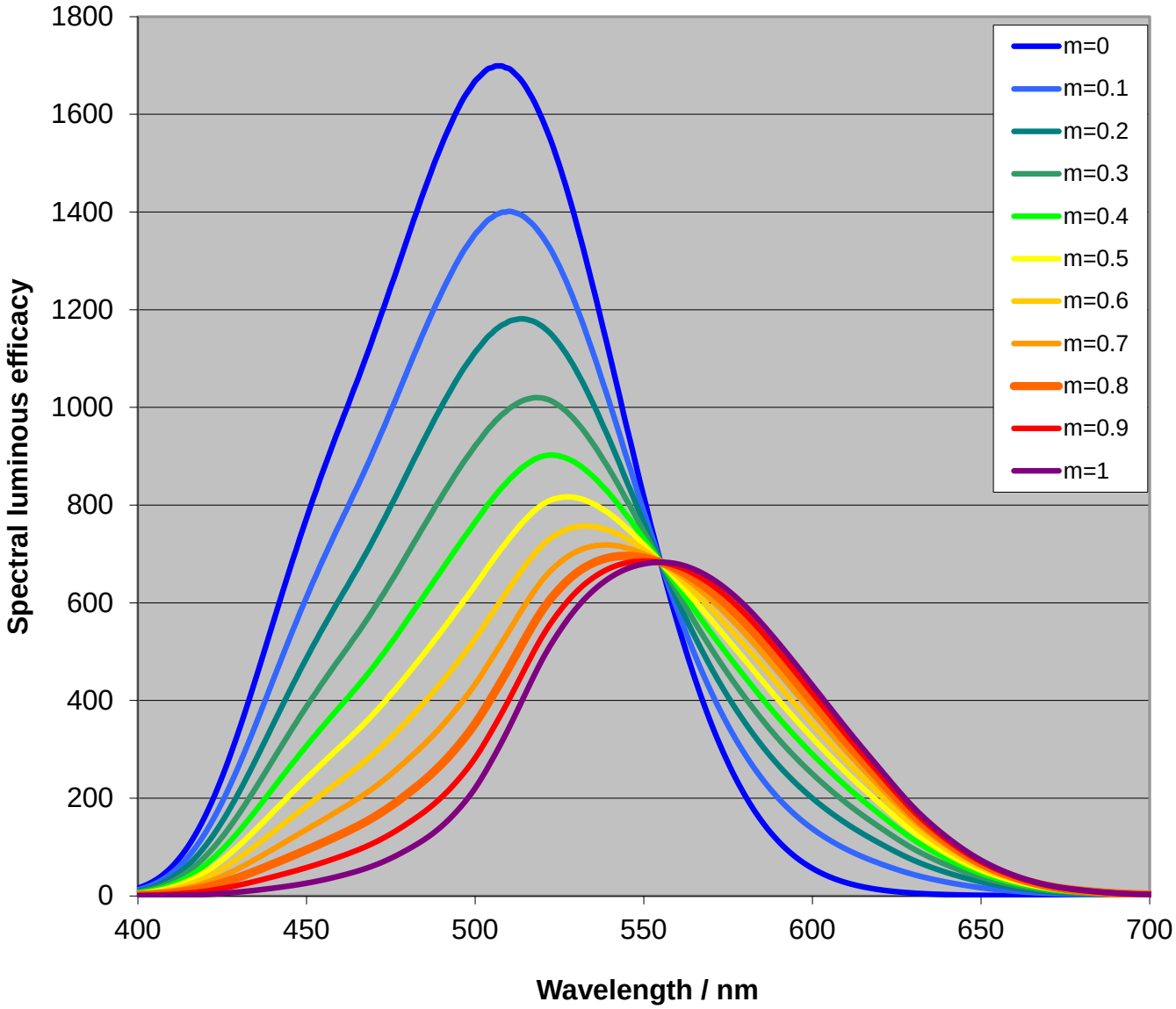
Spectral luminous efficacy functions

- Spectral weighting function depends on visual adaptation (determines value of *m*)
- Mesopic system provides method for calculating *m* from values of L_p and L_s (or from S/P ratio) for the adaptation field



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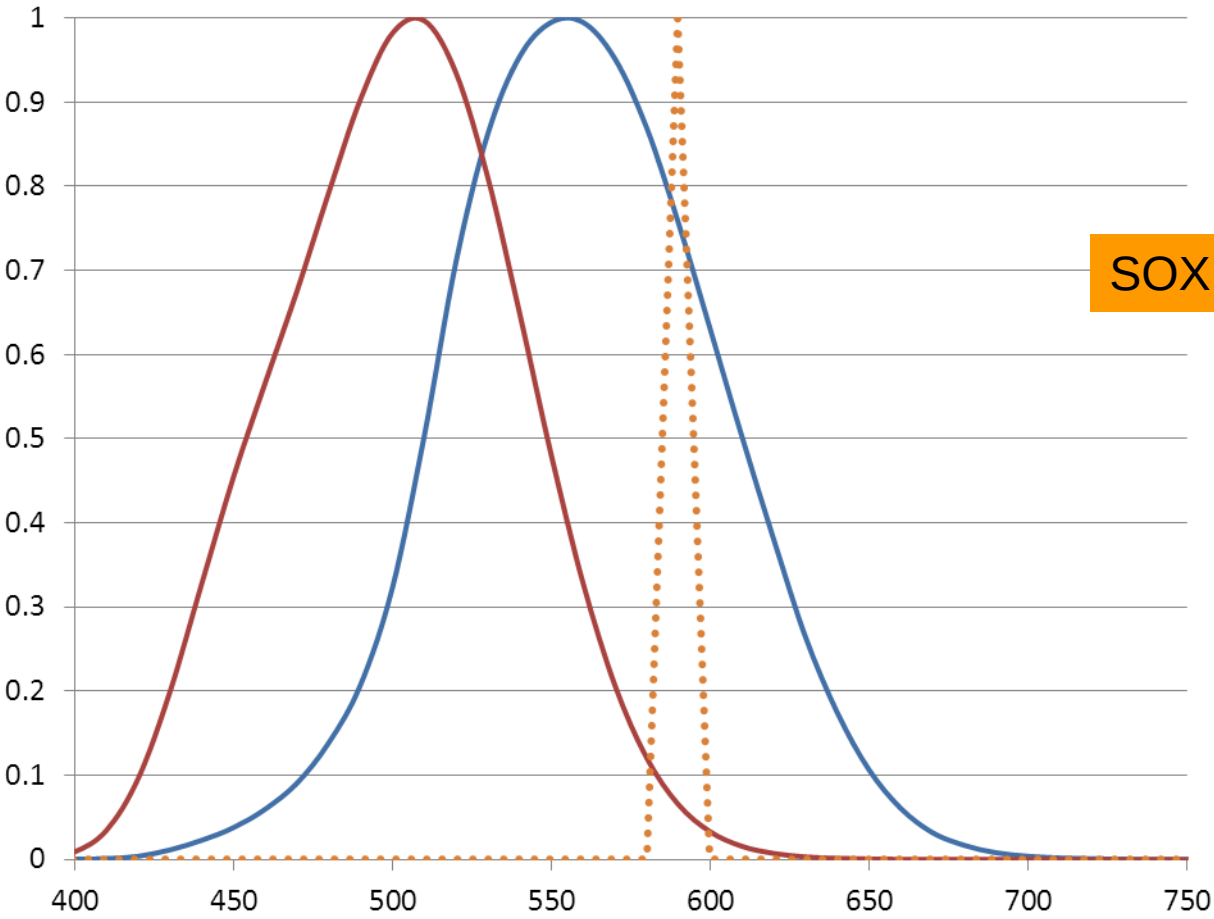
Relevance of mesopic photometry for SSL (1)

- In may important situations, eye is operating in mesopic regime
  - Emergency escape lighting; Marine signalling; Night-time driving
- Photopic values do not represent true visual effectiveness
- Potential for SSL to balance good colour rendering and high mesopic efficacy



SOX, S/P 0.23

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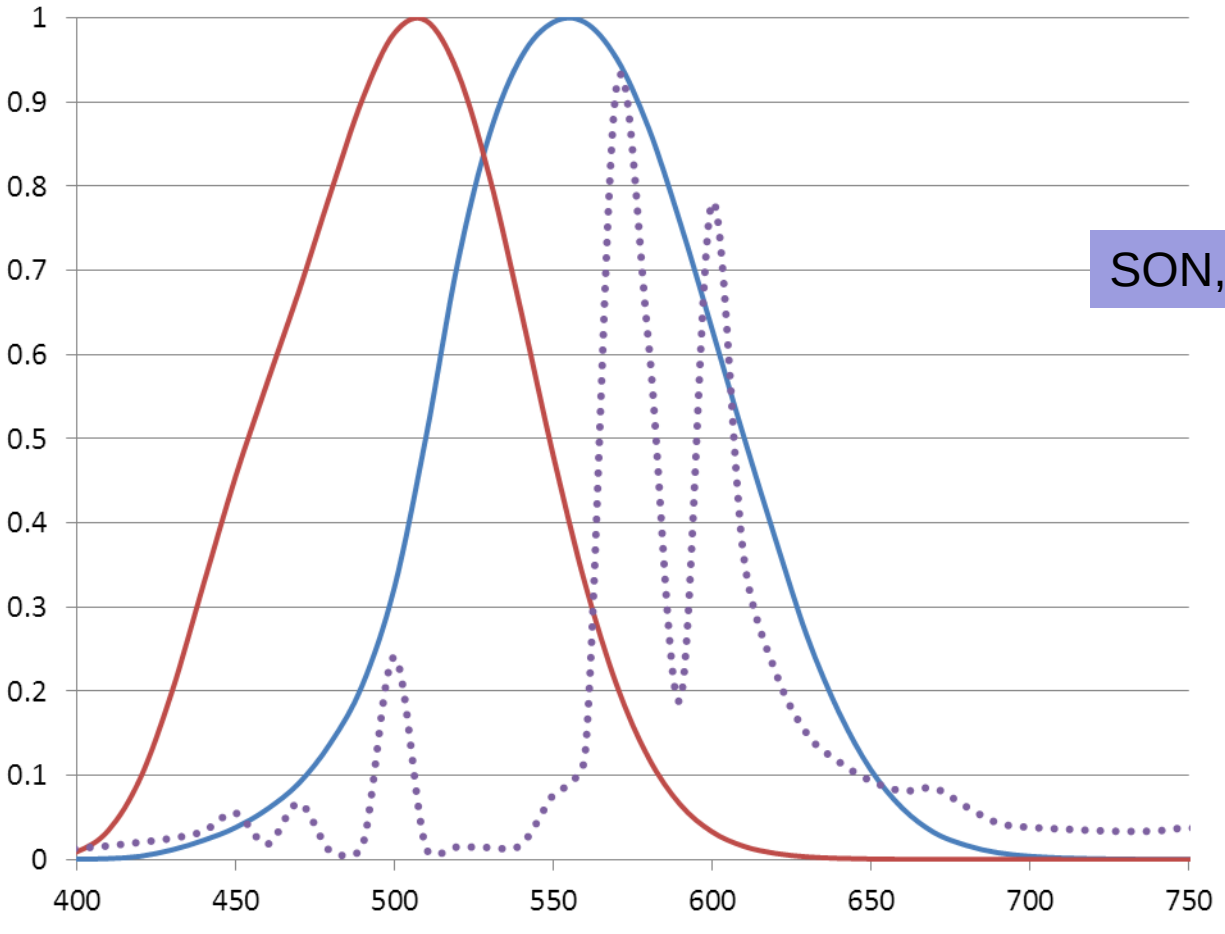

SON, S/P 0.65

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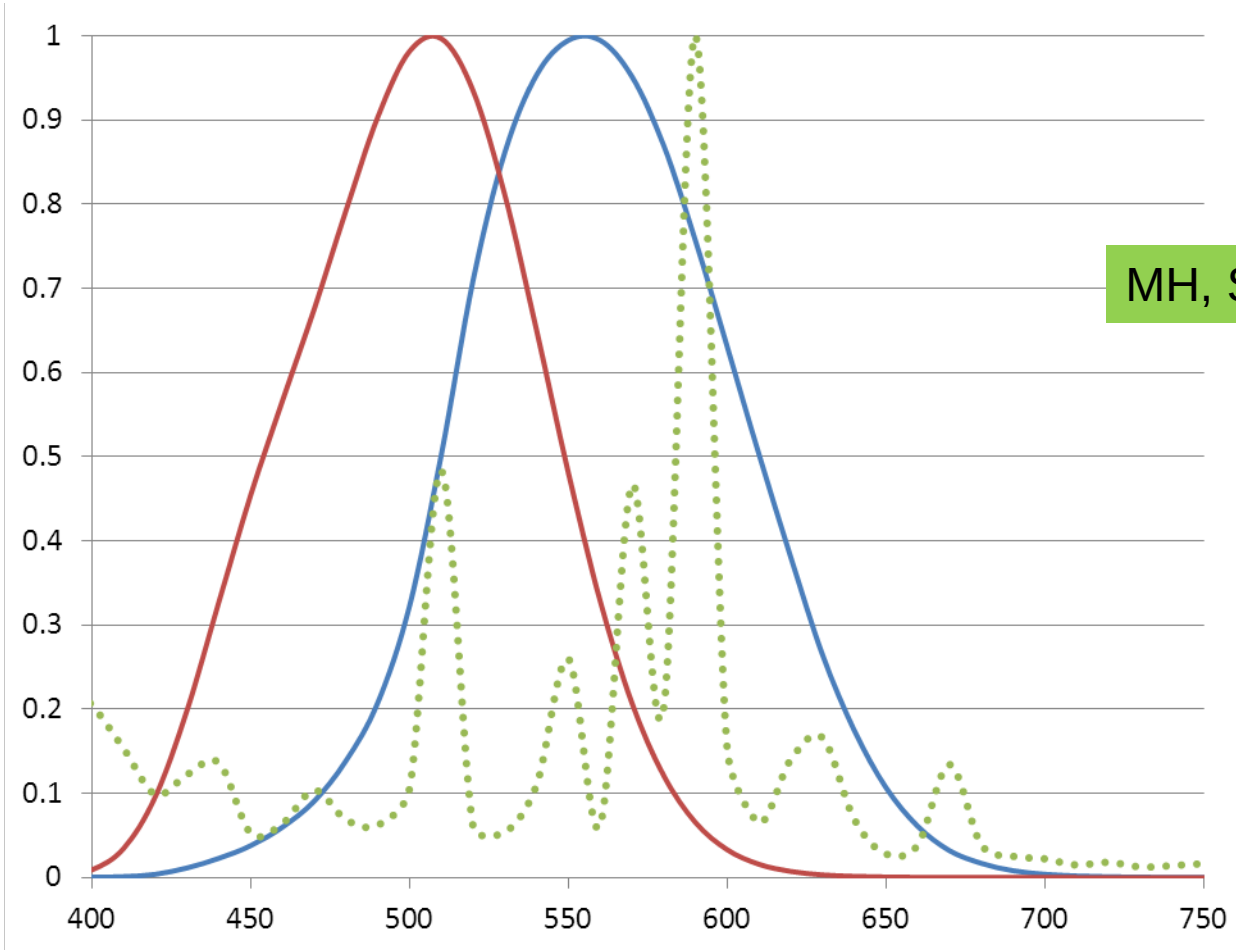

MH, S/P 1.6

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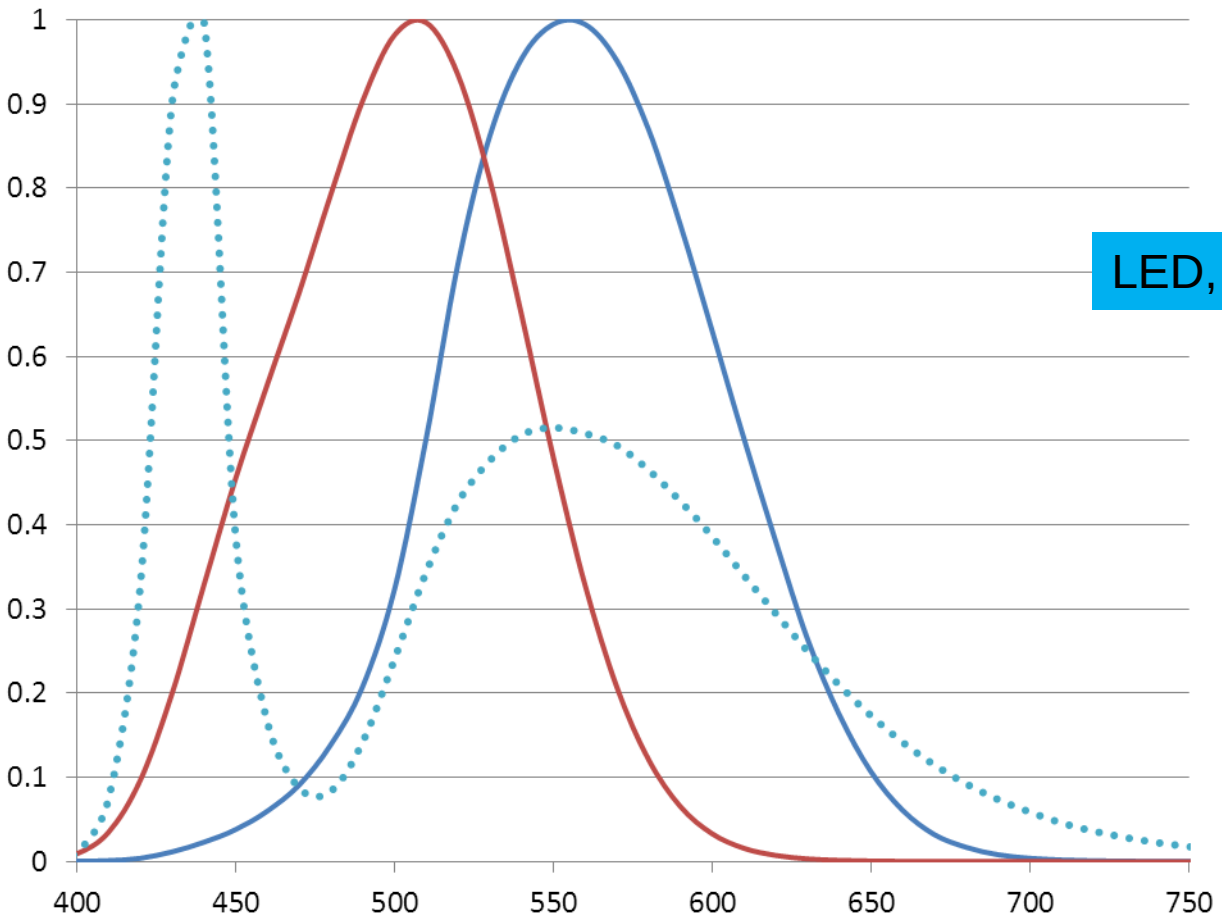

LED, S/P 2.6

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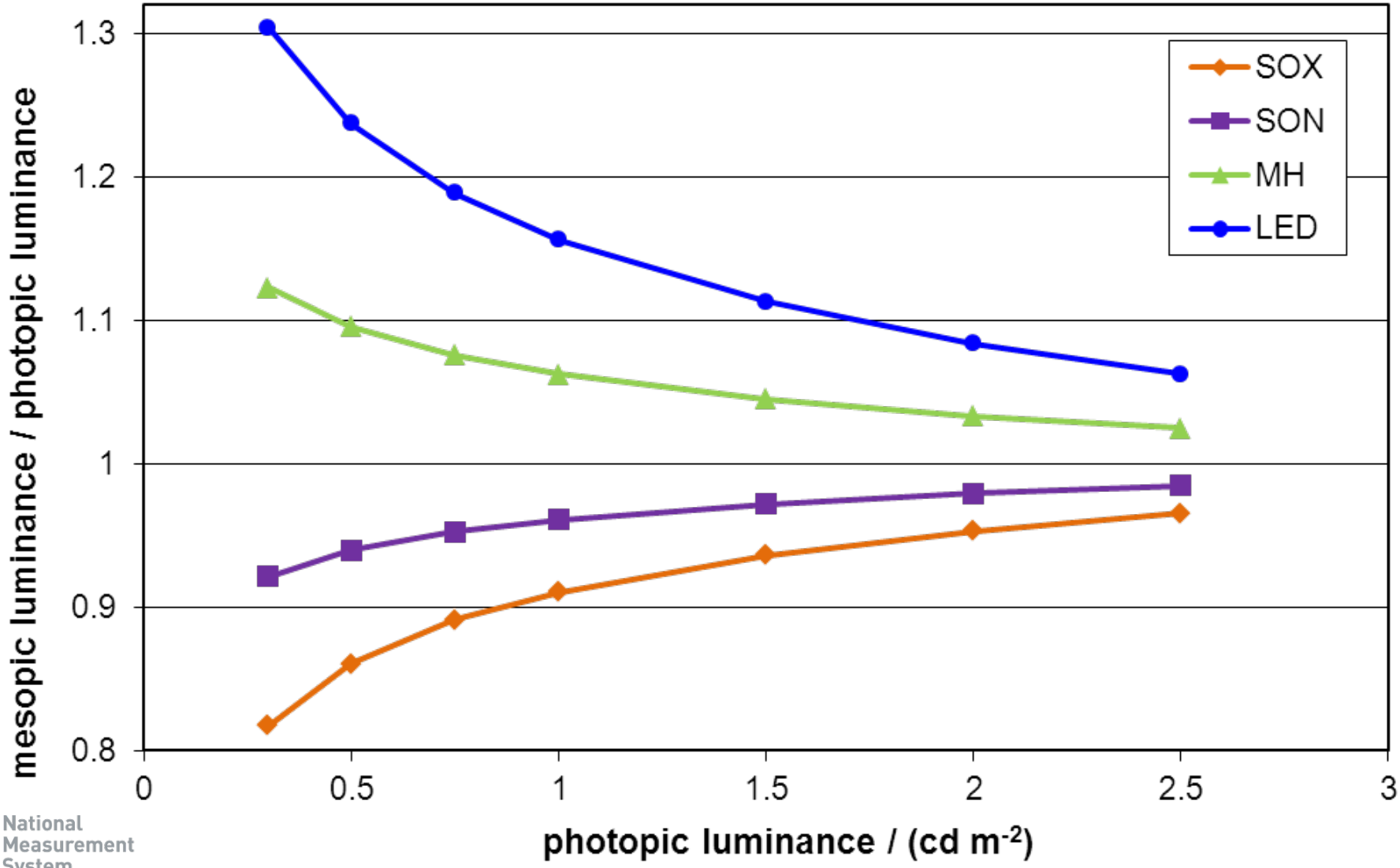
Relevance of mesopic photometry for SSL (2)



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Street lighting requirements

- Aid safe movement ($\Rightarrow$ aid detection of obstacles)
- To enhance pedestrian perception of safety ($\Rightarrow$ increase brightness)
- Increase ability to make informed decisions on intent of other street users ($\Rightarrow$ recognition of facial expressions)
- To improve visual appearance ($\Rightarrow$ visual acceptability / preference)

Is mesopic photometry all that matters?

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Metrics for implementation of mesopic lighting from CIE TC4-48

	Obstacle detection	Perceived brightness	Assessing intent	Acceptability
CIE mesopic photometry or S/P ratio	✓	✓	✓	
R_a			✓	✓
Further research			✓	✓

Proposed metrics for quantifying street lighting performance: CIE mesopic photometry combined with high R_a

Using the mesopic system: step 1 – determine adaptation conditions

$$L_{\text{mes}} = \frac{683}{V_{\text{mes}}(555)} \int L_{\text{e}}(\lambda) V_{\text{mes}}(\lambda) \mathrm{d}\lambda$$

$$V_{\text{mes}}(\lambda, m) = \frac{1}{M(m)} \{ m V(\lambda) + (1-m) V'(\lambda) \}$$

- Must determine *m* before can calculate any mesopic quantity
- *m* depends on the visual adaptation of the eye, which varies with:
  - luminance of the adaptation field
  - spectral characteristics of the adaptation field (S/P ratio, R_{SP})

Using the mesopic system: step 2 – calculate *m* and L_{mes}

Two methods are given in CIE 191:2010:

1. Iterative approach

$$m_0 = 0.5$$

$$L_{mes,n} = \frac{m_{(n-1)}L_p + (1-m_{(n-1)})L_s(683/1700)}{m_{(n-1)} + (1-m_{(n-1)})(683/1700)}$$

$$m_n = 0.7670 + 0.3334\log_{10}(L_{mes,n})$$

Repeat until *m* converges

2. Tables giving values of *m* and L_{mes} as a function of photopic luminance and light source S/P-ratio (R_{SP}= L_s/L_p)

Using the mesopic system: step 3 – calculate other mesopic quantities

Other mesopic quantities can be calculated using the adaptation coefficient *m*

$$Q_{\text{mes}} = \frac{683}{V_{\text{mes}}(555)} \cdot \frac{1}{M(m)} \cdot \left[m \int Q(\lambda)\, V(\lambda) d\lambda + (m-1) \int Q(\lambda) V'(\lambda) d\lambda \right]$$

$$Q_{\text{mes}} = \frac{683}{V_{\text{mes}}(555) \cdot M(m)} \cdot \left[m Q_{\text{P}} + (m-1) Q_S \right]$$

Or

$$Q_{\text{mes}} = \frac{m Q_{\text{P}} + (1-m) \cdot Q_{\text{S}} \cdot \left(\frac{683}{1700} \right)}{m + (1-m) \cdot \left(\frac{683}{1700} \right)}$$

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Issues for implementation of mesopic photometry

- System provides photometric values in mesopic region based on visual adaptation (photopic luminance and S/P ratio of adaptation field)
- Does NOT state what is relevant adaptation field
  - Depends on application?
  - CIE JTC-1 working on this for outdoor lighting
- Does NOT state how measurements should be made, how quantities other than luminance should be calculated or how measurement results should be expressed
  - CIE TC2-65 working on this
- Does NOT state how the system fits within the SI system
  - CIE JTC-2 (CIE-CCPR) working on this
- Does not indicate what other considerations are important for key applications, especially road lighting
  - CIE TC4-48 report on this (under ballot)

Work of CIE JTC-1 (1)

- What is the size, shape and position of the adaptation field?
  - Where is attention concentrated?
  - How much of the visual scene should be considered?
  - Does luminance of area surrounding fixation area influence adaptation?

Eye tracking studies for drivers and pedestrians
Lab-based experiments to evaluate effect of surround luminance

Work of CIE JTC-1 (2)

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- Are all areas within (or surrounding) the defined adaptation field equally important?
  - Do non-uniformities within the defined field have an impact?
  - Do small, intense sources outside main area of fixation influence adaptation?

Pupil size studies when driving at night
Measurements of luminance at fixation point when driving at night
Lab-based experiments to determine influence of glare sources

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Work of CIE JTC-1 (3)

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- How do transient effects affect adaptation?
  - How to allow for fact that conditions change as observer moves (e.g. oncoming headlights when driving)?
  - How to allow for fact that gaze is constantly shifting?

Eye tracking experiments for different types of road
Pupil size studies when driving

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CIE JTC-1 results to date

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- Most eye fixations in 20° x 10° ellipse centred in front of driver
- Type of road / driving situation has large influence on fixation points
- Local adaptation dominates over surround luminance
- Glare sources also have an influence on adaptation
- Large luminance variations occur in real driving situations
- Large changes in pupil size occur in real driving situations

Work of CIE TC2-65

Practical implementation of mesopic photometry from a measurement perspective

Two initial priorities:

- To ensure correct use of terms and units for mesopic photometry.
- To provide guidance for manufacturers regarding the specification of product performance in the mesopic range.

Guidance relating to measurement procedures and instrumentation requires recommendations from JTC-1 on the size, shape and location of the adaptation field to be used

- Work on these aspects should wait for recommendations from JTC-1

TC2-65: Mesopic quantities and units

Technical Note on photometric quantities and units

- Photometric units **DO NOT** depend on spectral luminous efficiency function used
- Qualifying descriptors **MUST NOT** be added to units
- Qualifying descriptors **MUST** be used with quantities to identify spectral luminous efficiency function used
- If a qualifying descriptor is not used, $V(\lambda)$ applies
- For quantities evaluated using $V'(\lambda)$ function, descriptor "scotopic" is sufficient, but **MUST** be used
- For mesopic quantities, adaptation condition **MUST** be stated using:
  - value of adaptation coefficient, *m*, or
  - photopic adaptation luminance, L_{adapt} and S/P ratio of adaptation field, R_{SP}

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Key message: Must not use "mesopic lumen", "mesopic candela" etc!

TC2-65: Specifying product performance

- Intention is to provide guidance on how to specify product performance
- Need to avoid misleading information
  - It is not possible to specify a unique value for quantities such as the mesopic luminous flux of a lamp; mesopic quantities depend on visual adaptation and are not an intrinsic property of the lamp, luminaire etc.
- Standardised approach needed, especially for luminous flux
  - Still under development
  - Photopic luminous flux and S/P ratio?

Other issues in CIE TC2-65

- How to convert between luminance and illuminance for applications such as residential street lighting **design** (not measurement) in the context of mesopic photometry?
- Some guidance on use of CIE system for mesopic photometry in road and street lighting already appearing (e.g. TC4-48, UK ILP and BS, IES-TM-12, ….)
  - Need for this TC to review this published guidance to identify any potential measurement issues?
- Measurement instrumentation is already being developed
  - Need to develop recommendations for calibration and use now, before JTC-1 completes work?

$$L = q_0 E = \frac{\rho}{\pi} E$$

Conclusions / next steps

- More research needed to determine optimum size, shape and position of adaptation field
  - 20° x 10° ellipse centred in front of driver most likely
- Existing standards for street lighting (and other applications) need revision for mesopic system
  - Follow CIE TC4-48 approach?
- Transient effects and glare need to be considered in lighting design but are difficult to predict or allow for in real driving situations
- Guidance on quantities and units to be published shortly
- Calculations of illuminance from luminance should use q_0=0.07
- Guidance on calibration and use of new instrumentation likely to be required before CIE JTC-1 completes work

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