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Spectral vs Broadband Measurements of Sources for UV Disinfection

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Overview

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Introduction: What we need to know

I. Source Spectra

II. Action Spectra

III. Approaches to Instrumental Measurement

IV. Advantages of Spectral vs Broadband Measurement

V. Review & Conclusions

Introduction: What we need to know

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- **Purpose:** To model the efficacy of a source / irradiation system for surface disinfection

- **Essential Components of the Model:**
  - Characteristics of the Source System: Spectral Power Distribution
  - Response of the Pathogen: Action Spectrum

- **Challenges:**
  - Diverse types of Source
  - Diverse pathogens

I. Source Spectral Distribution

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- **The Ultraviolet region of the Electromagnetic Spectrum**
  - Distinguished by Wavelength & Photon Energy

- **UV subregions have distinct characteristics:**
  - UVA
  - UVB
  - **UVC***
  - Vacuum UV

Region of interest for Disinfection

- **Sources have varied spectral distributions**
  - among UV subregions
  - within a given region, e.g., the UVC

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Two different sources with the same total UVC content
but different UVC spectral distributions
can have very different germicidal efficacy.

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- **Definition: Action Spectrum**

- **Examples of Action Spectra**
  - Luminous Efficacy — Photometry
  - Erythemal Response — SPF Measurement
  - Germicidal Efficacy — *

- **Interaction of Source and Action Spectra**

  - *Consider two UVC sources with different peaks….*

action spectrum

function representing the relative spectral effectiveness of optical radiation, for a specified actinic effect, in a specified system; also referred to as: actinic spectrum efficiency….

Equivalent term: "spectral weighting function"

NOTE 1 The normalized action spectrum is the wavelength dependence of the inverse of the dose of monochromatic radiation required to induce a certain (biologic) response; the action spectrum is commonly normalized to a value of 1 at the wavelength of "maximum action", i.e., where the smallest dose suffices to induce the required effect.

KEY CONCEPTS: ACTION SPECTRUM

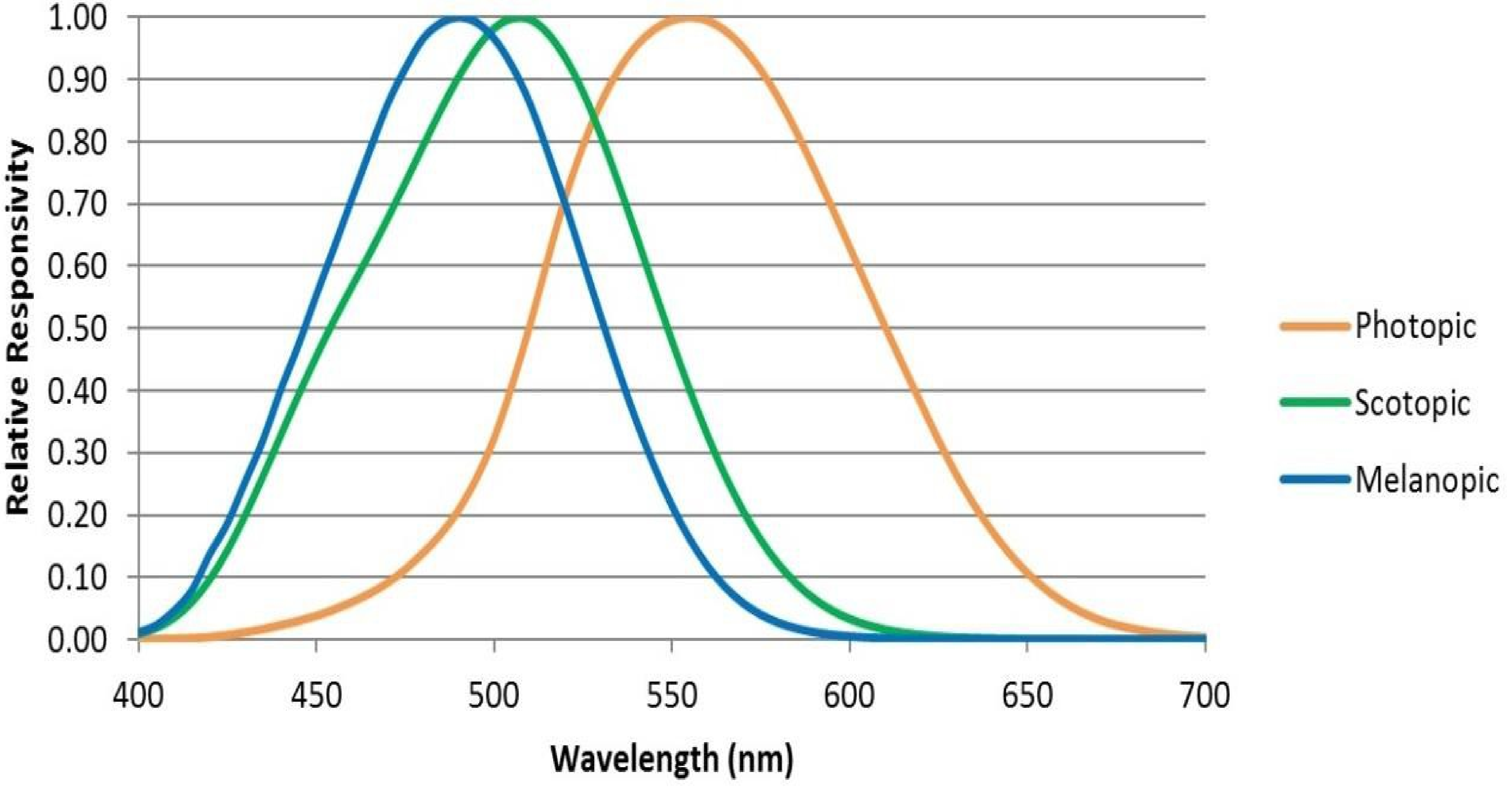
- Relative spectral effectiveness
- Specified actinic effect
- *for* Specified system / conditions

- Applied as a "spectral weighting function"

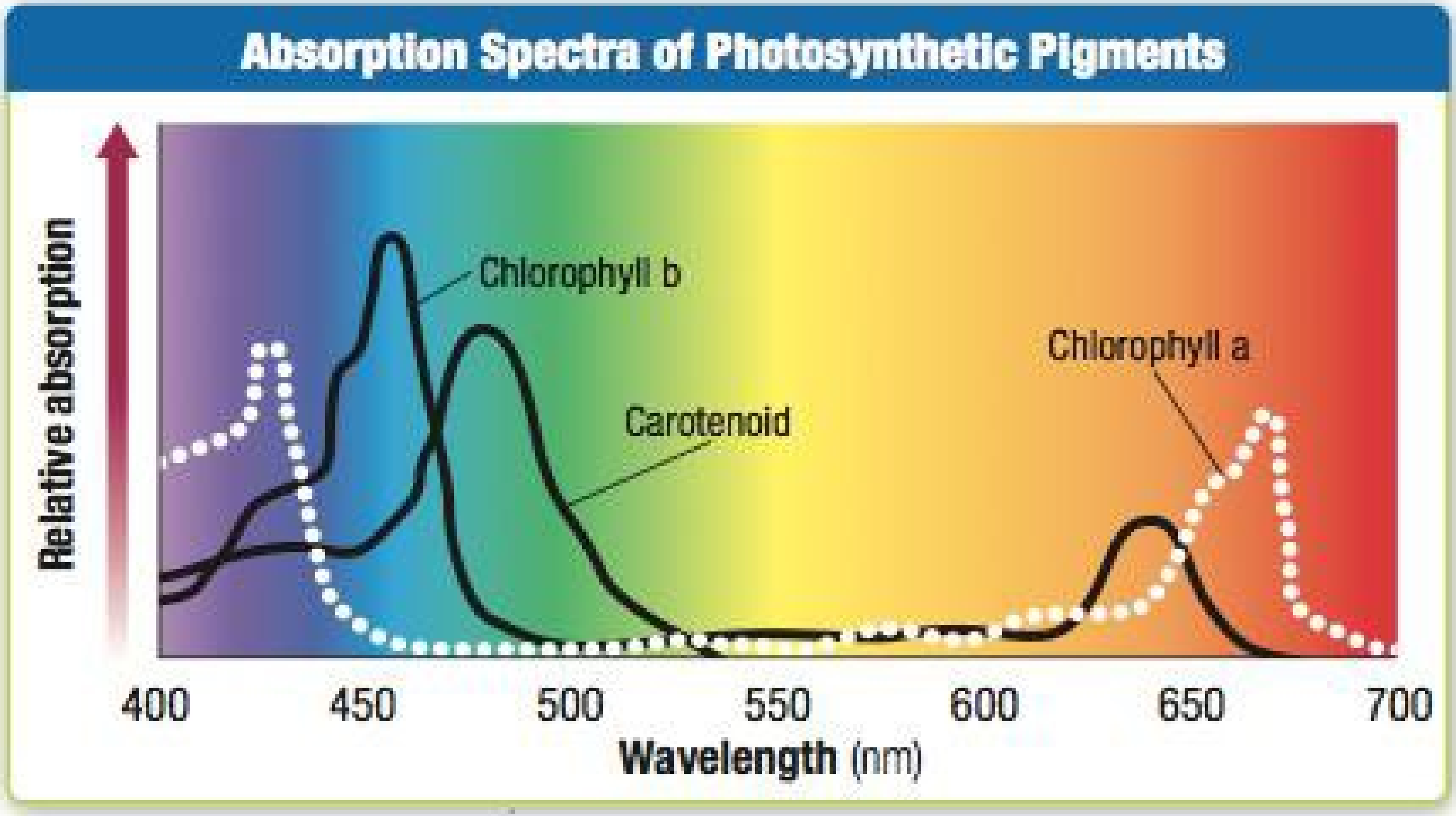
Examples of Action Spectra

• Luminous Efficacy	Photometry
• ipRGC Response	Circadian Regulation / Human Centric Lighting
• Photosynthetic Action Spectra	Horticultural Lighting
• Erythemal Response	SPF Measurement
• Germicidal Efficacy	Disinfection

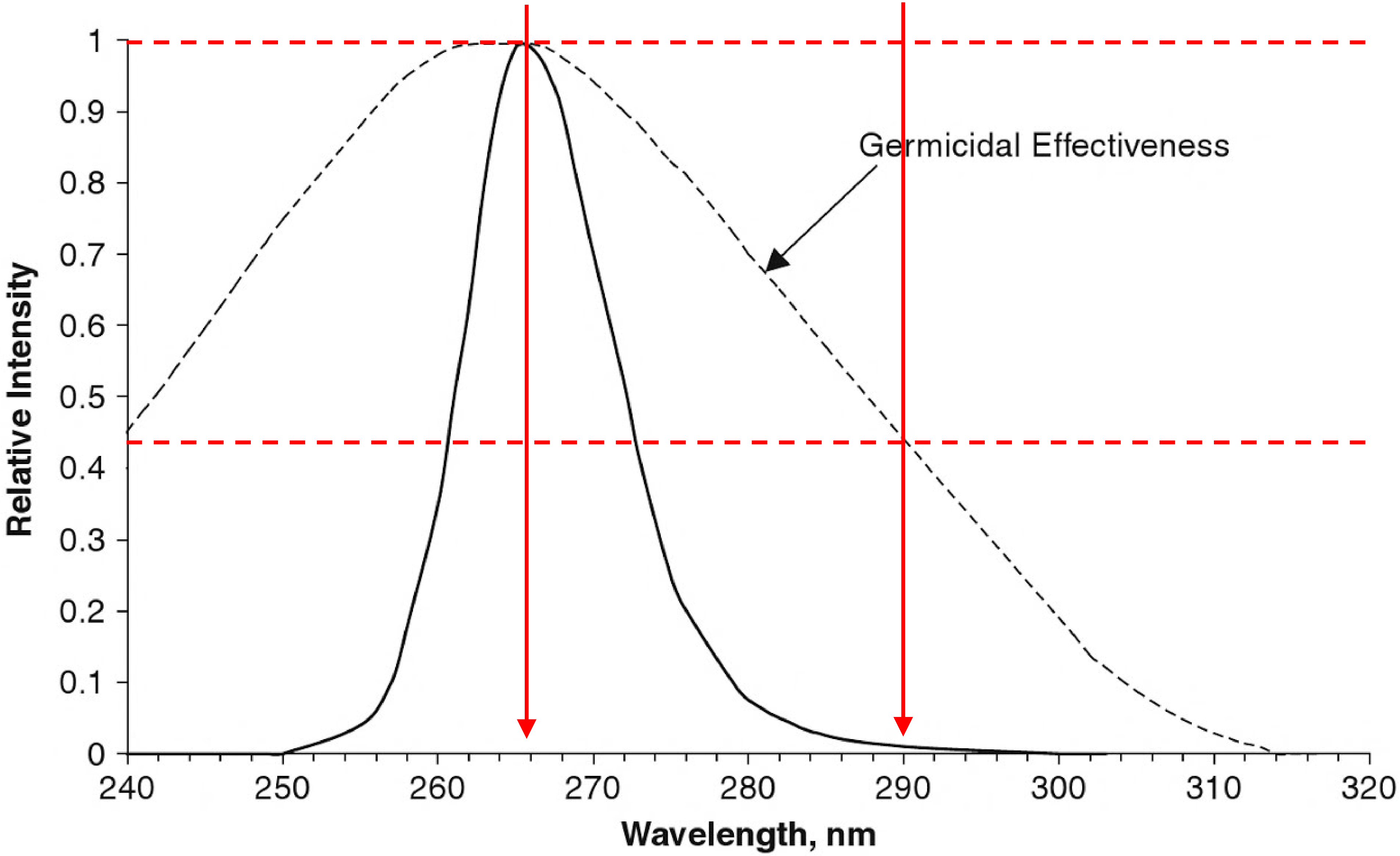
Human Centric Lighting / Circadian Lighting / Biodynamic lighting

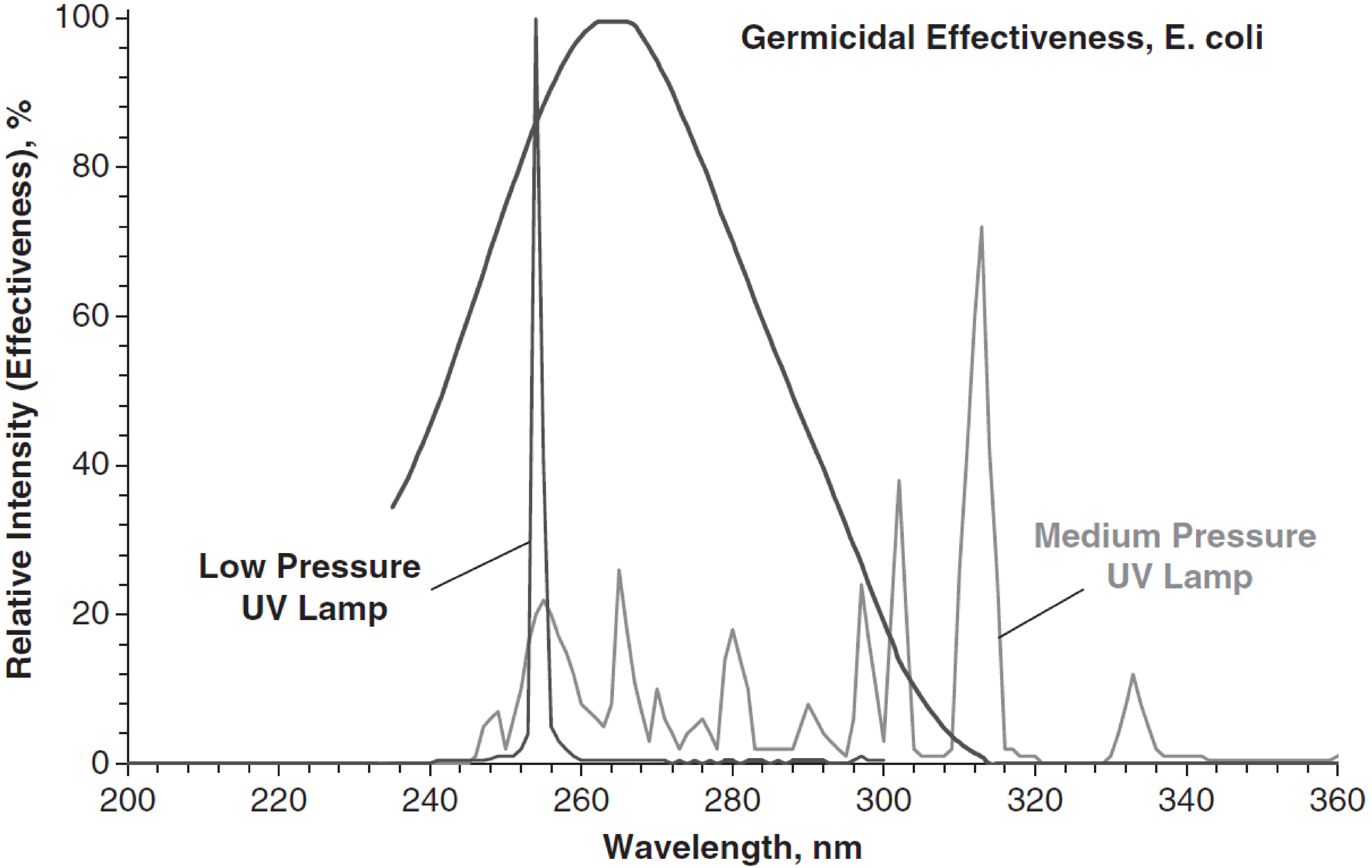


Horticultural Lighting



Interaction of Source and Action Spectra: *Two UVC Sources with different peaks*




Germicidal Effectiveness, E. coli
Low Pressure UV Lamp
Medium Pressure UV Lamp
Relative Intensity (Effectiveness), %
Wavelength, nm
0
20
40
60
80
100
200
220
240
260
280
300
320
340
360

Two different sources with the same total UVC content
but different UVC spectral distributions
can have very different germicidal efficacy.

III. Approaches to Instrumental Measurement

A. Spectral vs Broadband Measurements

- Units of Measurement
- Basic Instrument Design

B. Simple Radiometers vs Filter Radiometers

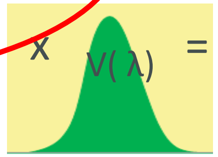
A. Unfiltered detector – arbitrary spectral response
B. Bandpass filter for absolute radiometry in a specified band (e.g. UVC)
C. Response-matching filters for specific applications (action spectra)

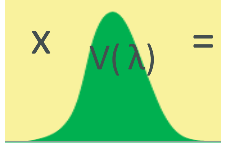
C. "Effective" Radiometry

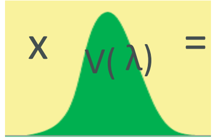
- "Response Matching" filter – physical simulation of an action spectrum
- Spectral Mismatch

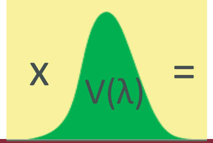
Radiometric and Photometric Units

Radiometric Quantity	Radiometric Unit	Photometric Quantity	Photometric Unit
Irradiance	W/m^2	Illuminance	lux
Radiance	$W/(sr.m^2)$	Luminance	cd/m^2
Radiant intensity	W/sr	Luminous intensity	cd
Radiant flux	W	Luminous flux	lumens



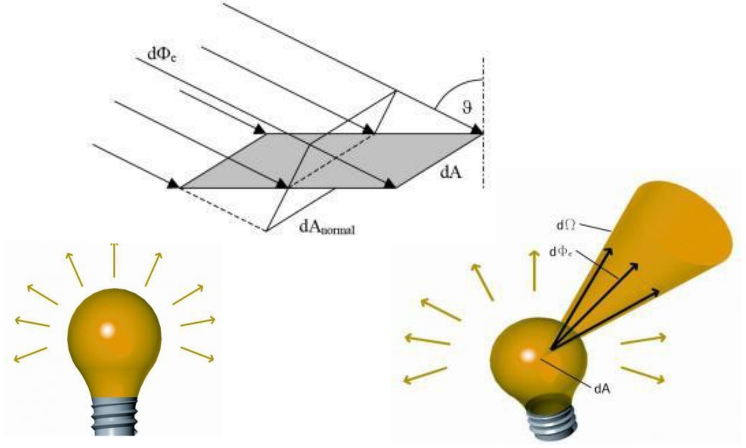






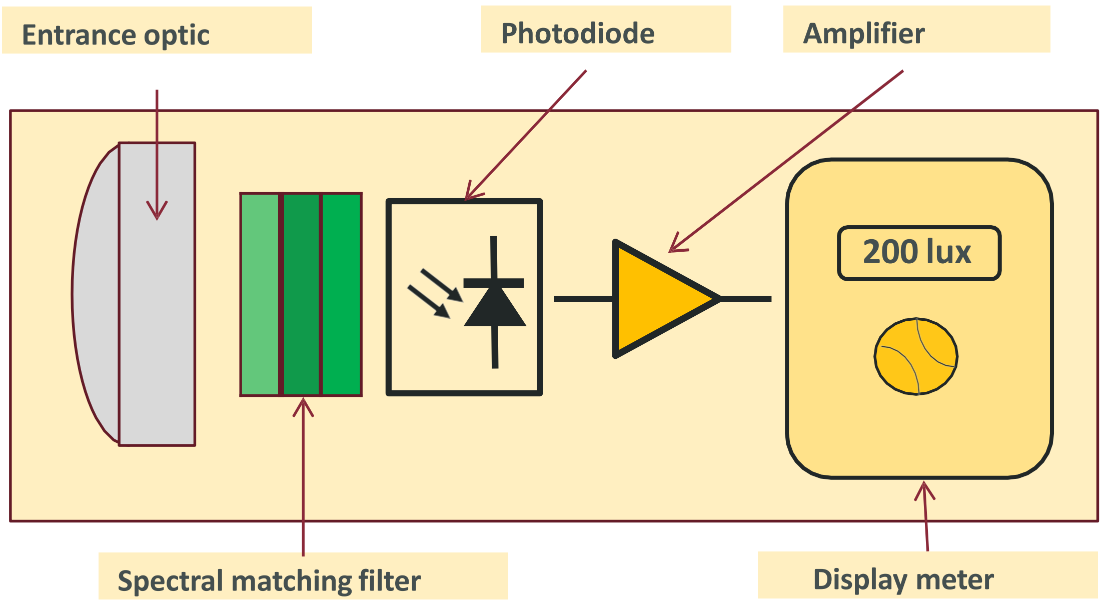
Visible light metrics or ‘photometric’ measurements are referred to as illuminance, luminance, luminous intensity, and luminous flux.

An appropriate entrance optic is required for the different metric, e.g. diffuser for lux, sphere for lumens, lens for cd…. But all require the application of the photometric response to the absolute ‘radiometric’ measurement.



www.gigahertz-optik.de/en-us/basics-light-measurement

Schematic diagram – Radiometer / Photometer



Performance Metrics for Photometers and Radiometers

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How do we assess the performance of a photometer or radiometer?

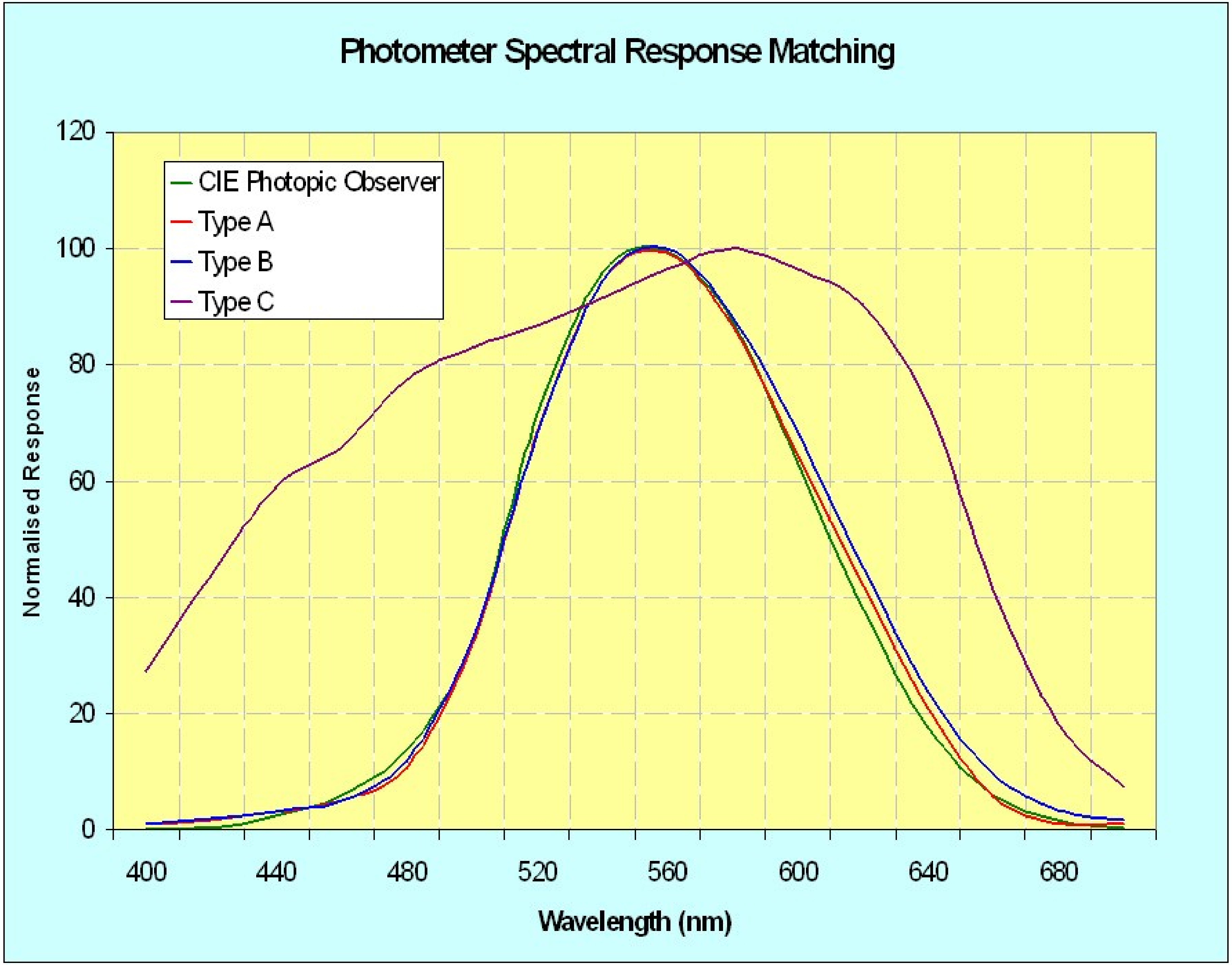
In photometry, there is a comprehensive set of quality indices defined, and analogous metrics could be defined for UV radiometers. They include spectral mismatch, angular response, linearity, temperature dependence, etc. Of these, **spectral mismatch** is generally the most critical.

Similar quality indices are defined for radiometers.

ISO/CIE 19476:2014 (CIE S 023/E:2013) Characterization of the performance of illuminance meters and luminance meters

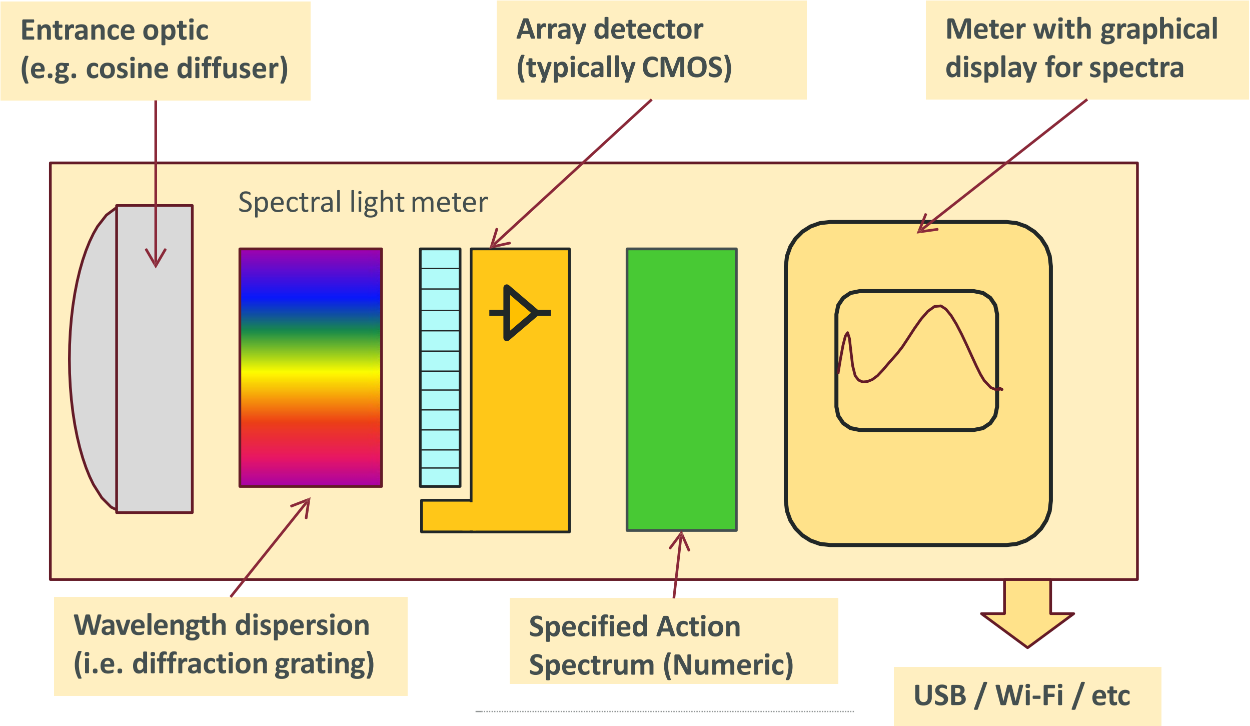
Quality Indices	Notation
V(λ) Mismatch	f_1'
UV Response	f_{UV}
IR Response	f_{IR}
Cosine Response (i)	f_2
Linearity	f_3
Display Unit	f_4
Fatigue	f_5
Temperature Dependence	$f_{6,T}$
Humidity Resistance	$f_{6,H}$
Modulated Light	f_7
Polarization	f_8
Spatial Non-uniformity	f_9
Range Change	f_{11}
Focusing Distance (ii)	f_{12}

(i) Illuminance meters only *(ii) Luminance meters only*



Photometer Spectral Response Matching
CIE Photopic Observer
Type A
Type B
Type C
Normalised Response
Wavelength (nm)
0
20
40
60
80
100
120
400
440
480
520
560
600
640
680

Schematic diagram – Spectroradiometer



Spectroradiometers

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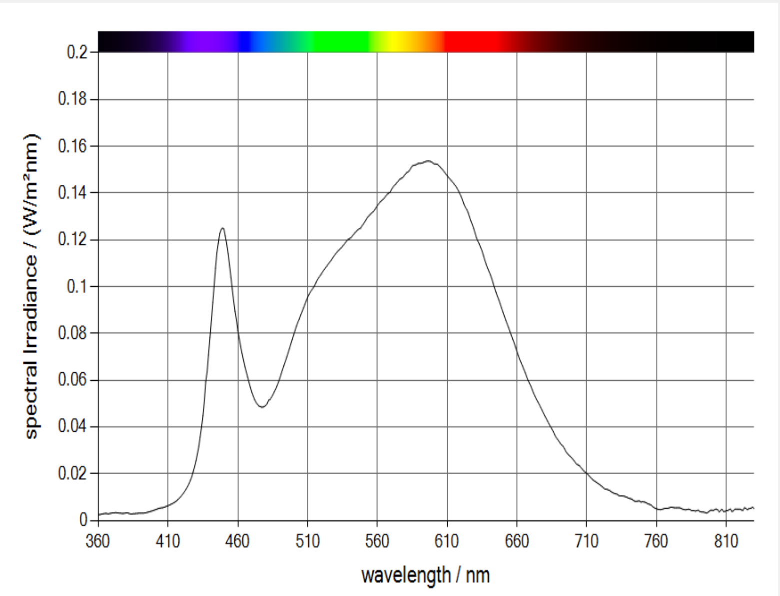
Once we have the absolute spectral data of a light source, we can do much more than just assess its efficacy in terms of a single specific action spectrum. We can asses its performance in terms of any given action spectrum, by application of the appropriate spectral weighting function.



Action Spectrum or Band of primary interest

Additional Quantities of interest

IV. Advantages of Spectral vs Broadband Measurement

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BROADBAND MEASUREMENT

Advantages

- Simplicity
- Cost

Disadvantages

- Spectral Mismatch Error
- Limited Application

SPECTRAL MEASUREMENT

Disadvantages

- Complexity
- Cost

Advantages

- Eliminates Spectral Mismatch
- Flexible Application

Review & Conclusions

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What we need to know: *Characteristics of Source and Pathogen*

I. Source Spectra *Diverse, and changing*

II. Action Spectra *Diverse, and emerging*

III. Spectral vs Broadband *Physical vs Mathematical Simulation*

IV. Advantages of Spectral vs Broadband Measurement

- *Both approaches can provide simple and effective solutions;*
- *Broadband solutions are economical, but have limitations;*
- *Spectral solutions are more rigorous, flexible, and… costly.*

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Thank you for your attention

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