Introduction to Photometry and Flicker

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LUND UNIVERSITY

Visual ergonomics group

Ergonomics and Aerosol Technology

DESIGN SCIENCES | FACULTY OF ENGINEERING, LTH

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Design Sciences

Department of Design Sciences covers six divisions:
- Ergonomics and Aerosol Technology
- Industrial Design
- Innovation Engineering
- Packaging Logistics
- Product Development
- Rehabilitation Engineering (Certec)

Lighting lab

Ergonomics and Aerosol Technology

DESIGN SCIENCES | FACULTY OF ENGINEERING, LTH

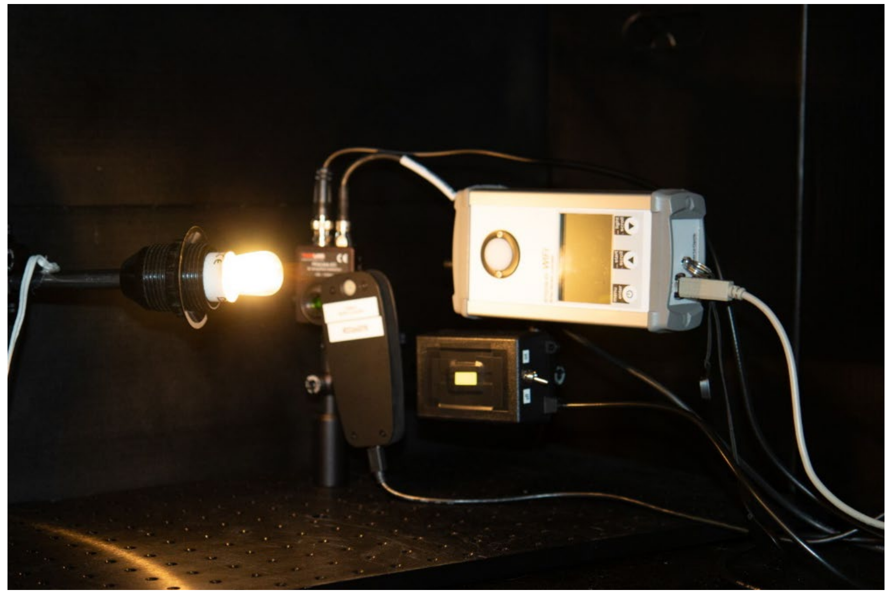
Environmental Psychology

Department of Architecture and Built Environment | LTH, Faculty of Engineering

Conducts lighting research with respect to human health and safety, regarding aspects such as:

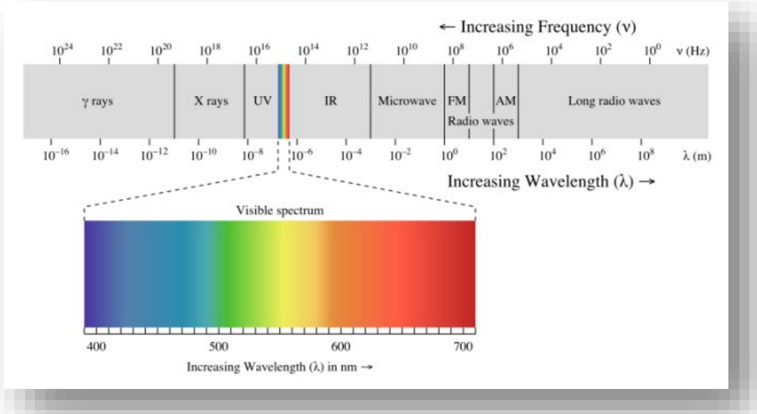
- Visual ergonomics
- Comfort
- Glare
- Flicker

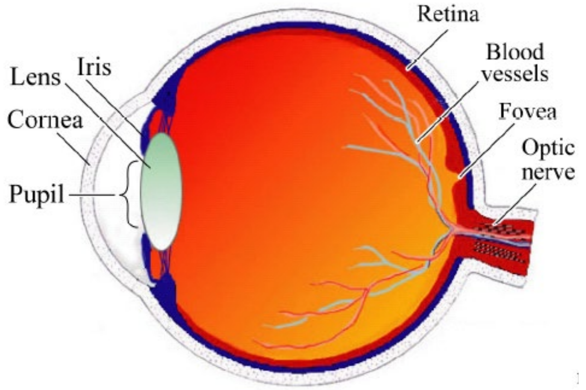
Houses a lighting lab for assessment of lighting conditions and light source perfomance, both in lab and in the field.

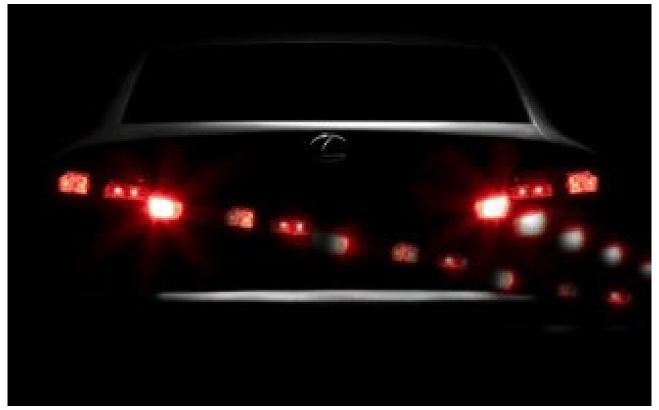


Outline

- Radiometry & Photometry
- Luminous Efficacy and ipRGC
- LED light with phosphors
- Flicker







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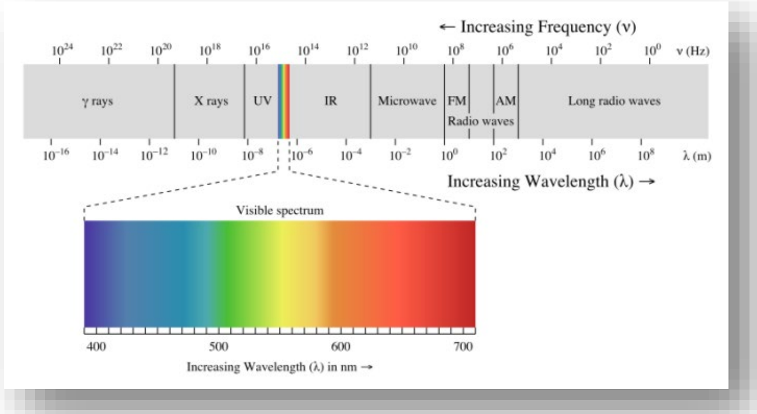
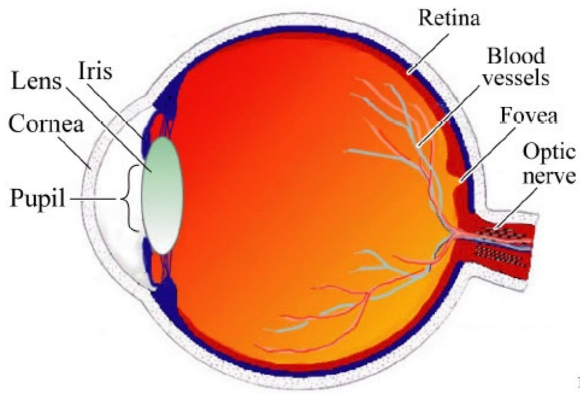
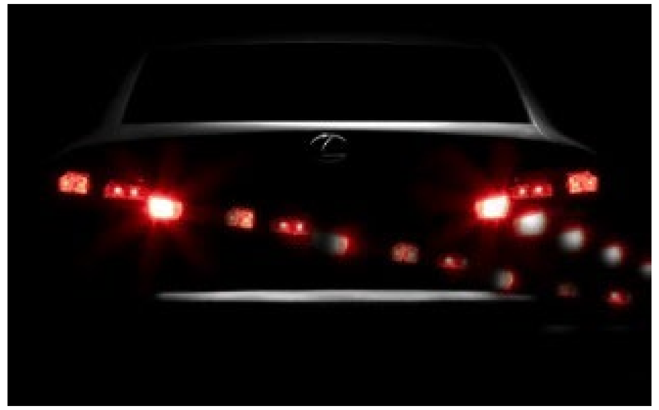






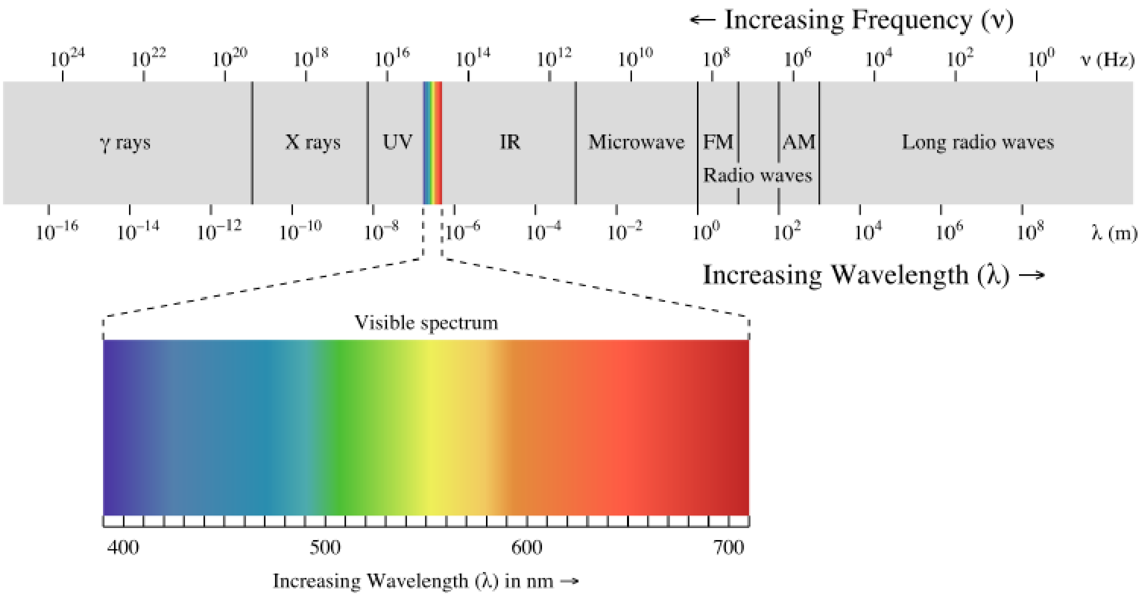
Radiometry and Photomety

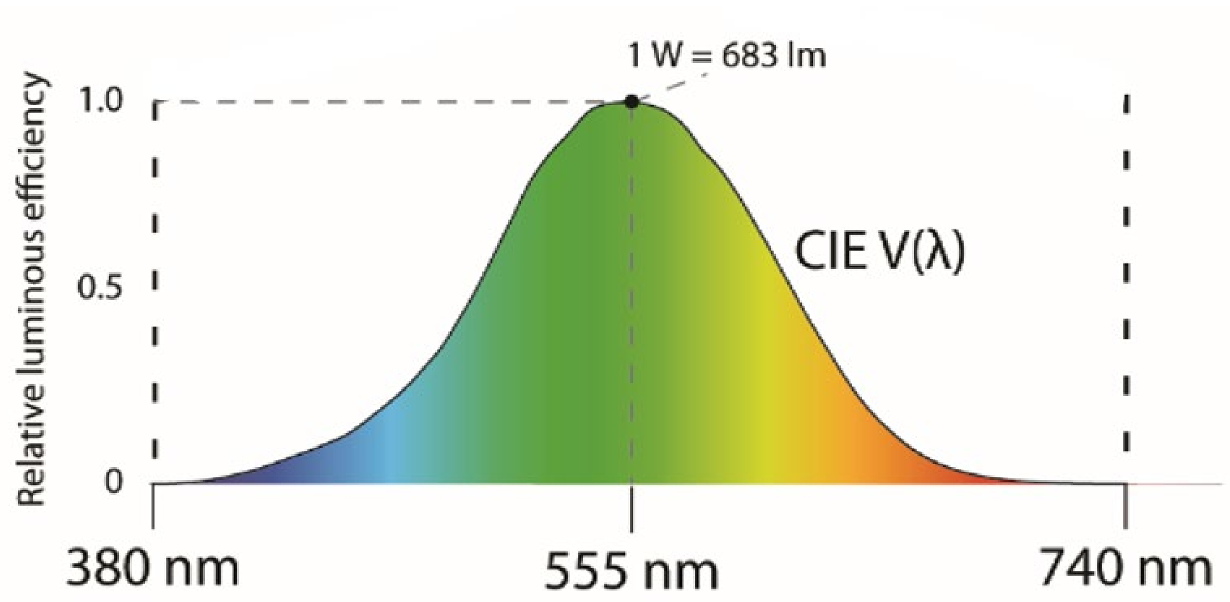
Radiometry:

the measurement of electromagnetic radiation

Photometry:

the measurement of electromagnetic radiation taking the human eye sensitivity into consideration





Example:

Quantity	*Radiant power (or flux)*
Symbol	Φ_e
Unit	*Watt [W]*

Example:

Quantity	*Luminous flux*
Symbol	Φ_v
Unit	*Lumen [lm]*

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Radiometry

- Radiant energy: Q_e [J]
- Radiant flux (power): $\Phi_e = \frac{dQ_e}{dt}$ [W]
- Radiant exitence (emitance): $M_e = \frac{d\Phi_e}{dA_1}$ [W/m^2]
- Radiant intensity: $I_e = \frac{d\Phi_e}{d\omega}$ [W/sr]
- Radiance: $L_e = \frac{dI_e}{dA_1 cos\theta_1}$ [W/m^2 sr]
- Irradiance: $E_e = \frac{d\Phi_e}{dA_2}$ [W/m^2]

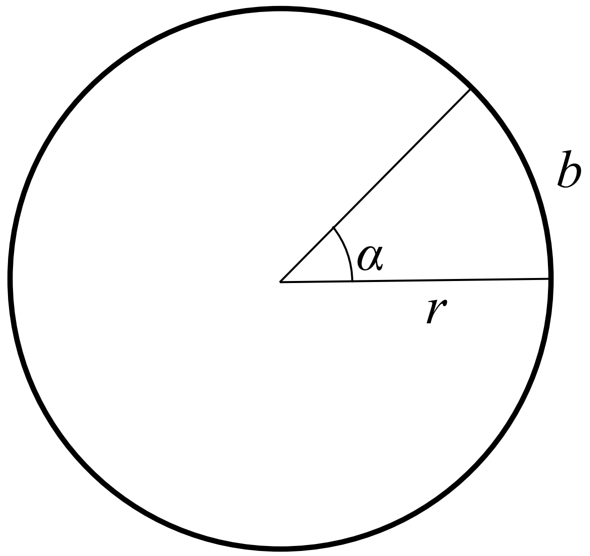
Solid angles and steradians

- A measure of field of view in space from a particular point

Definition of angle α in a plane:
$\alpha = \frac{b}{r}$ [radians (rad)] where

b = arc length and
r = radius.

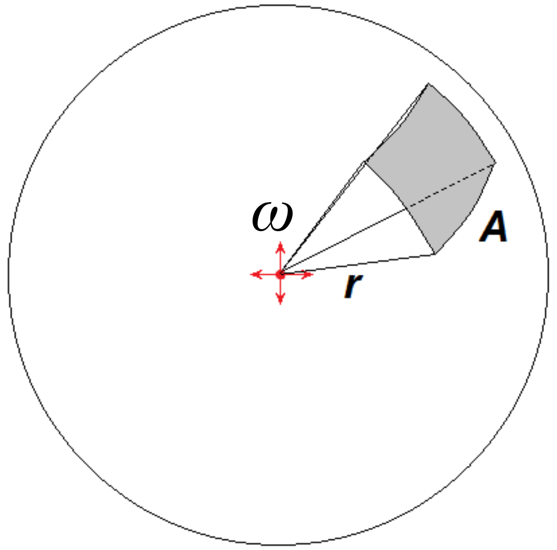
Whole circle => $\alpha = 2\pi$



Similarly…
Definition of the solid angle ω in space:
$\omega = \frac{A}{r^2}$ [steradian (sr)] where

A = area of segment of sphere and
r = radius of sphere.

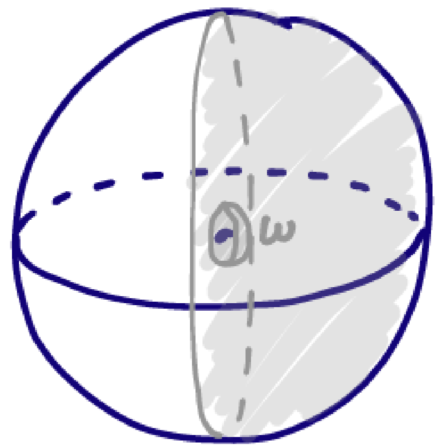
Whole sphere => $\omega = 4\pi$



Surface area A_{sph} of a sphere: $A_{sph} = 4\pi r^2$

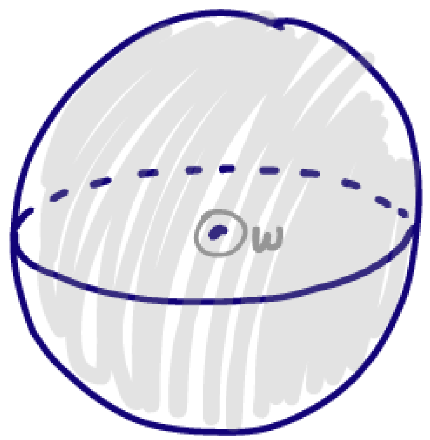
Solid angles and steradians

Ex. 1 – A solid angle covering half the space is 2π streradians

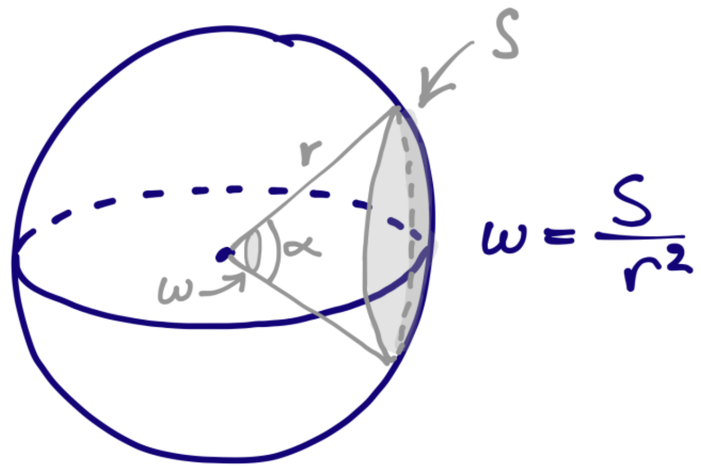


$$\omega = \frac{2\pi r^2}{r^2} = 2\pi$$

Ex. 2 – A solid angle covering the entire space is 4π streradians



$$\omega = \frac{4\pi r^2}{r^2} = 4\pi$$

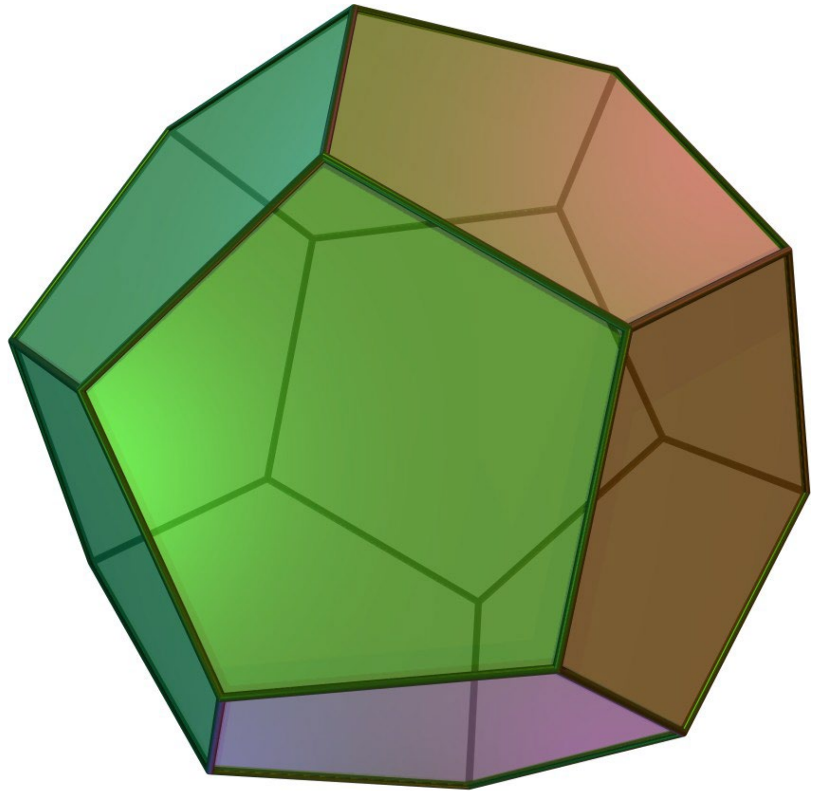


Solid angle ω from a symmetric angle α:

$$\omega = 2\pi\left(1 - \cos\left(\frac{\alpha}{2}\right)\right)$$

Solid angles and steradians

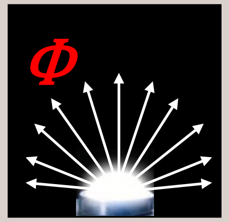
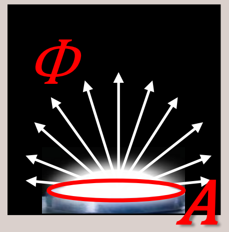
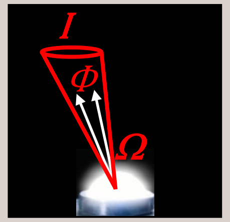
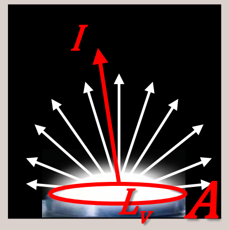
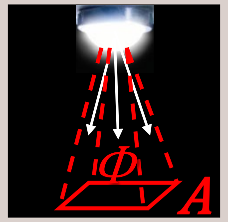
Dodecahedron: 12 pentagons



A dodecahedron can be used to illustrate the size of 1 steradian.

Since a dodecahedron consists of 12 equaly sized pentagons, and the solid angle covering the entire space is $4\pi \approx 12.57$ steradians, the solid angle covered by one pentagon is roughly 1 steradian.

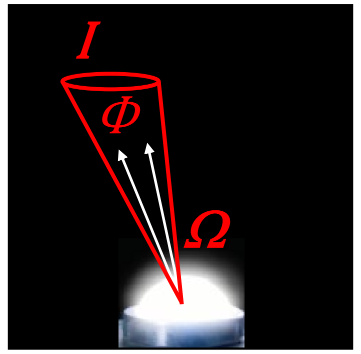
Radiometry and Photometry

						
	Energy	Power	Power per emitting surface	Power per solid angle	Intensity per projected surface	Recieved power density
Radiometry	*Radiant energy* Q_e *[J]*	*Radiant flux (or power)* Φ_e *[W]*	*Radiant exitance* $M_e = \Phi_e / A$ *[W/m²]*	*Radiant intensity* $I_e = \Phi_e / \Omega$ *[W/sr]*	*Radiance* $L_e = I_e / A$ *[(W/sr)/m²)]*	*Irradiance* $E_e = \Phi_e / A$ *[W/m²]*
Photometry	*Luminous energy* Q_v *[lm·s] (talbot)*	*Luminous flux* Φ_v *lumen [lm]*	*Luminous exitance* $M_v = \Phi_v / A$ *[lm/m²]*	*Luminous intensity* $I_v = \Phi_v / \Omega$ *candela [cd = lm/sr]*	*Luminance* $L_v = I_v / A$ *nit [cd/m²]*	*Illuminance* $E_v = \Phi_v / A$ *lux [lx = lm/m²]*
Explanation in terms of photometry.		The amount of light emitted from a light source.	The amount of light emitted from a luminous surface.	The intensity of a light source in a certain direction, given in luminous flux per unit solid angle.	The intensity of a luminous surface.	The amount of light that falls on a surface, given in luminous flux per unit area.

Luminous Intensity

Quantity	*Luminous Intensity*
Symbol	I_v
Unit	*candela [cd = lm/sr]*

- Luminous flux per solid angle: $I_v = \Phi_v / \Omega$
- Property of the *light source*
- The candela [cd] is a base unit in the SI system
- Definition (since 2019):
  "The candela, symbol cd, is the SI unit of luminous intensity in a given direction. It is defined by taking the fixed numerical value of the luminous efficacy of monochromatic radiation of frequency $540 \cdot 10^{12}$ Hz, K_{cd}, to be 683 when expressed in the unit lm/W."
- Old definition:
  "One standardized candle emits a luminous intensity of 1 candela"
- Intermediate definition (1967-1979):
  "The candela is the luminous intensity, in the perpendicular direction, of a surface of 1/60 cm^2 of a black body at the temperature of freezing platinum (2045 K) under a pressure of 101 325 N/m^2 (1 atm).

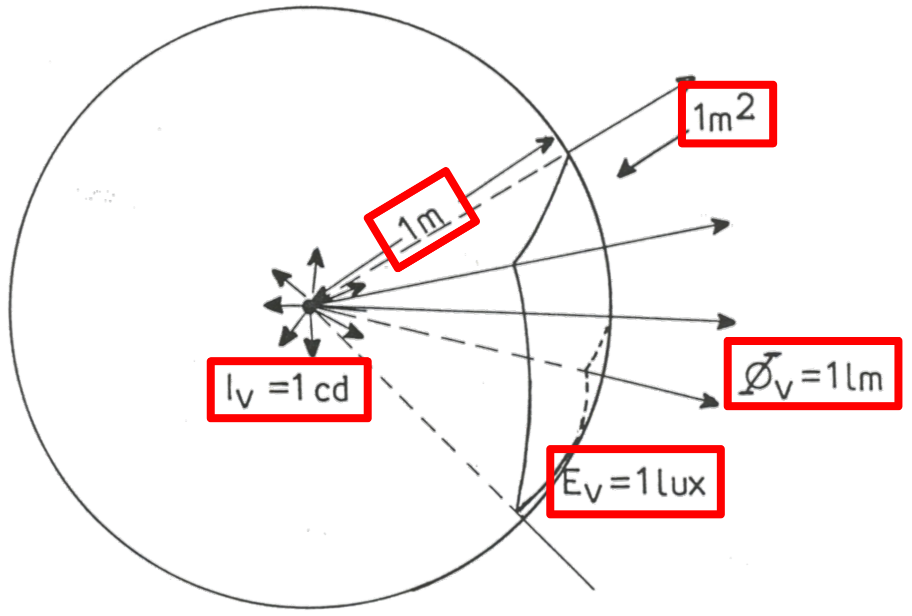


Luminous Intensity

Consider a point light source:

Luminous Intensity I_v = 1 cd = 1 lm/sr

In all directions



Consider the soild angle of 1 steradian, i.e. an area of 1 m^2 at a distance 1 m from source:

$$\Omega = \frac{A}{R^2} = \frac{1m^2}{(1m)^2} = 1sr$$

This area is then illuminated by the **luminous flux, Φ_v**, of 1 lumen:

$$\Phi_v = I_v \cdot \Omega = 1\frac{\text{lm}}{\text{sr}} \cdot 1 \text{ sr} = 1 \text{ lm}$$

The **illuminance, E_v**, on this area is then 1 lux:

$$E_v = \frac{\Phi_v}{A} = \frac{1\text{lm}}{1\text{m}^2} = 1 \text{ lx}$$

The total luminous flux in all directions is 4π lumen, or 12.57 lumen.

Luminous Intensity

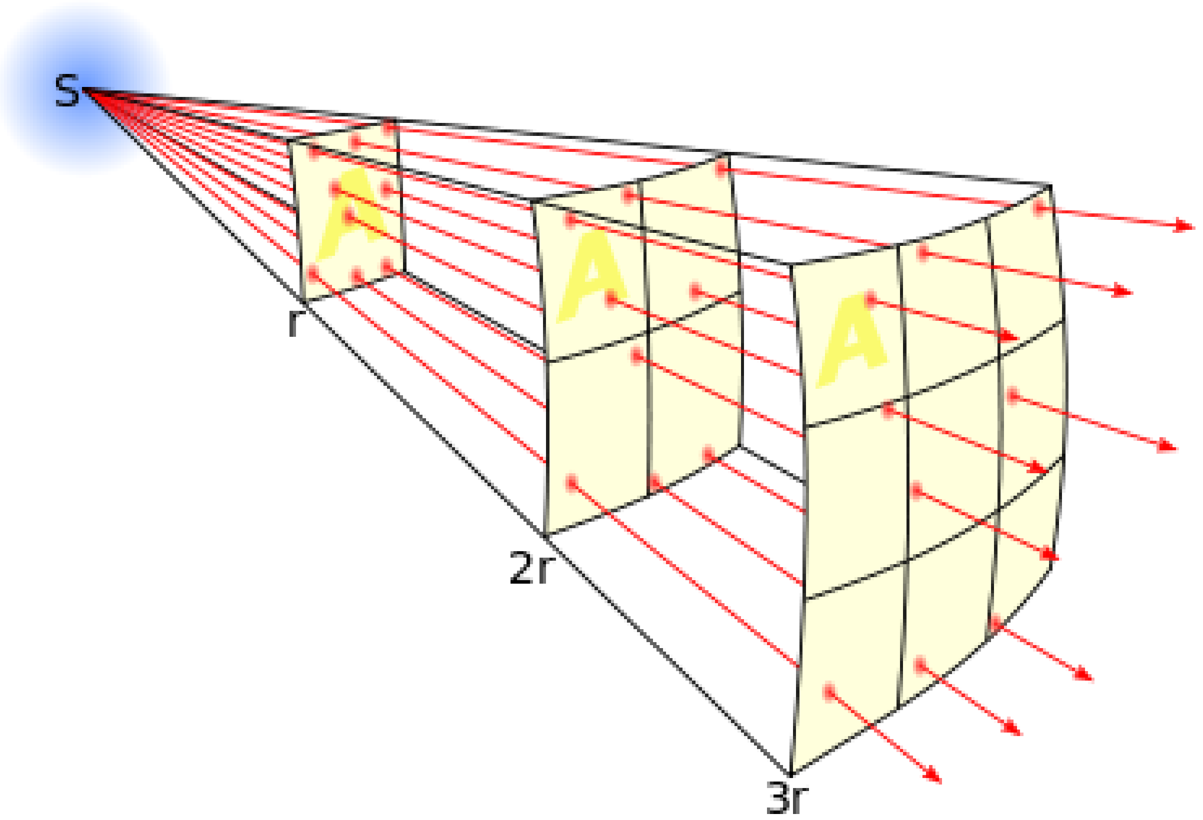
For a light source emitting 1 cd in all directions, the total luminous flux is 4π lumen, or 12.57 lumen.

Test:
A candle light in an integrating sphere.

Measured: ~10 lumen

1 cd in all direction (almost).

Inverse Square Law



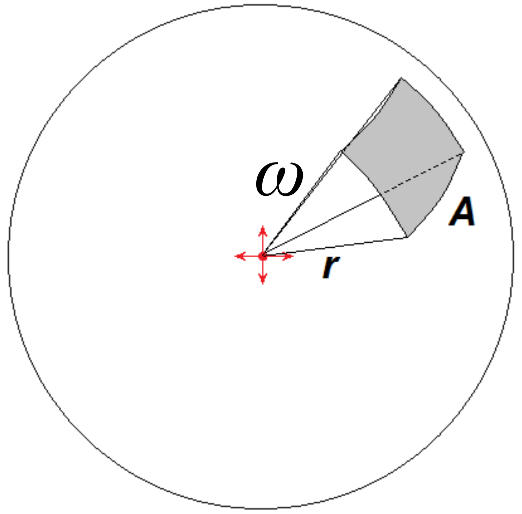
For light radiating from a point source:

- The illumination on a surface is inversely proportional to the square of the distance from the source.
- An object twice as far away, receives only ¼ the illuminance. Three times the distance gives 1/9 the illuminance.

$$\omega = \frac{A}{r^2}$$

$$A_{sph} = 4\pi r^2$$

$$\omega_{spr} = 4\pi$$



Illuminance E_v on A: $E_v = \frac{\Phi_v}{A}$

Luminous flux: $\Phi_v = I_v \cdot \omega$ (From $I_v = \frac{\Phi_v}{\omega}$)

Solid angle definition: $\omega = \frac{A}{r^2}$

Leads to: $E_v = \frac{\Phi_v}{A} = \frac{I_v \cdot \omega}{A} = \frac{I_v \cdot 4\pi}{4\pi r^2} = \frac{I_v}{r^2}$

Inverse Square Law: $E_v = \frac{I_v}{r^2}$

$$E_1 \cdot d_1^2 = E_2 \cdot d_2^2$$

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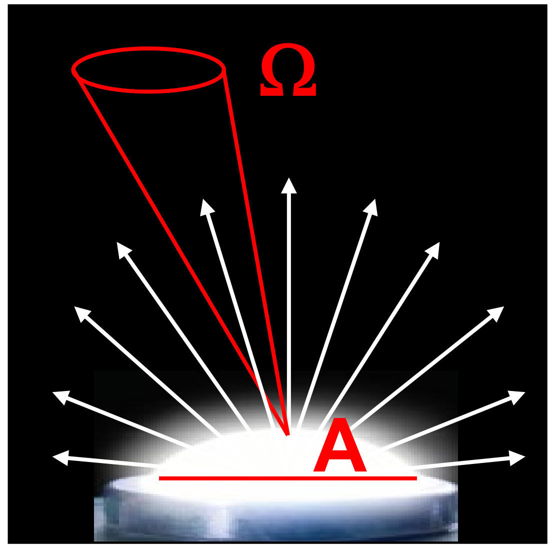
Luminance

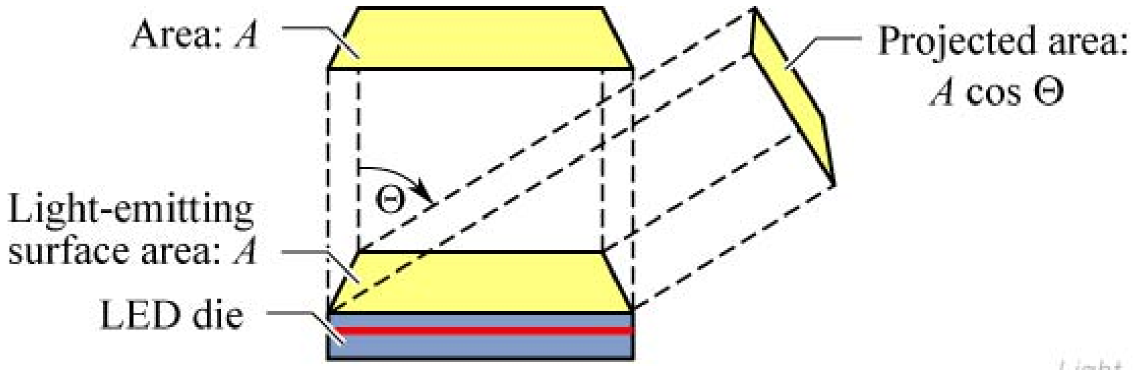
Quantity	*Luminance*
Symbol	L_v
Unit	*cd/m² (nit)*



- Luminous intensity per <u>*projected*</u> unit area

$$L_v = \frac{I_v}{A}$$

- Property of the *emitting surface*



Device	L_v [cd/m^2]
LCD display	100 – 300
Moon	2 500
Clear blue sky	8 000
OLED	100 - 10 000
Eye is blinded	> 10^5
HB LED	10^6 – 10^8
Sun (zenith)	$1.65 \cdot 10^9$

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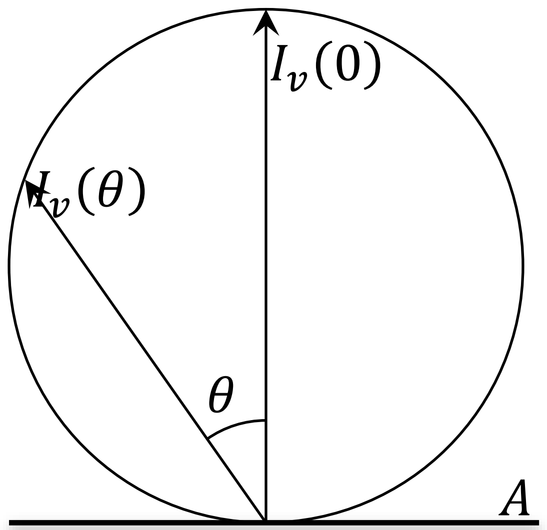
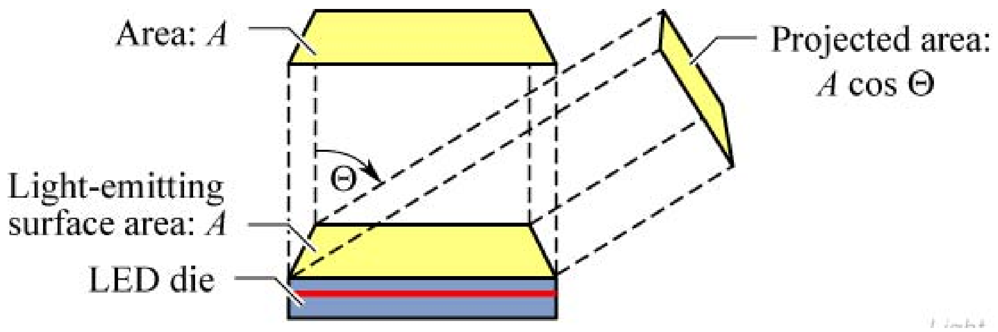
A Lambertian source





Lambert's cosine law: $I_v(\theta) = I_v(0)\cos\theta$

Projected area: $A\cos\theta$

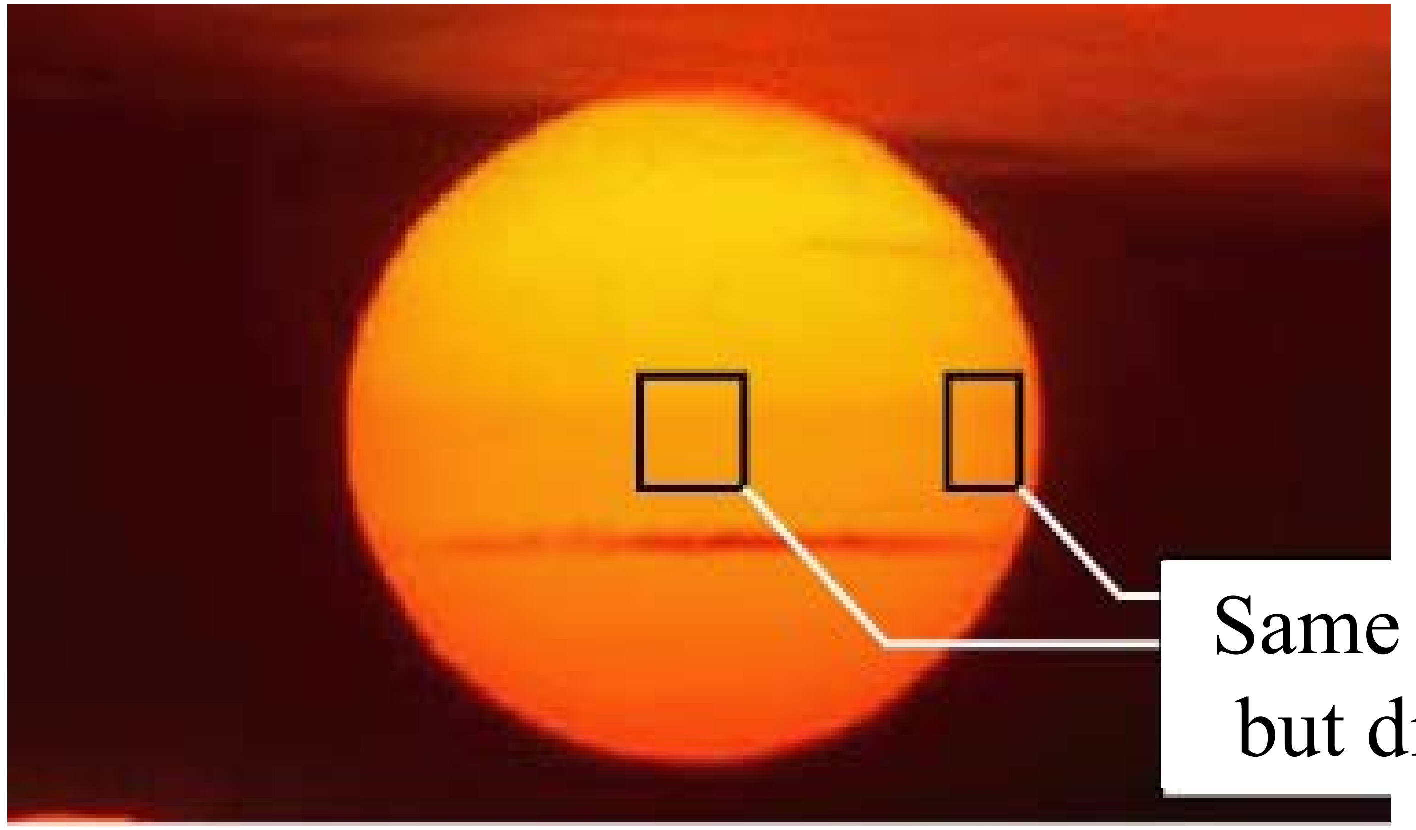
Consider then that the luminance, L_v, is luminous intensity, I_v, devided by projected surface, $A\cos\theta$

$$L_v = \frac{I_v}{A\cos\theta}$$

This leads to the fact that the luminance, L_v, is independent of viewing angle:

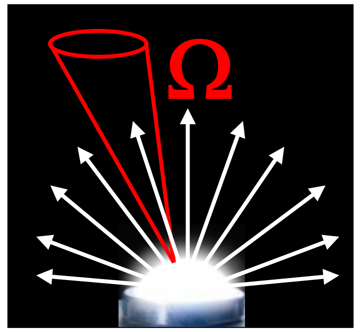
$$L_v = \frac{I_v(\theta)}{A\cos\theta} = \frac{I_v(0)\cos\theta}{A\cos\theta} = \frac{I_v(0)}{A} = constant$$

A Lambertian source



Same brightness (luminance)
but different viewing angle.

”Brightness”



- Brightness is a public more understood quantity rather than photometric terms

- Brightness of sources:

  - ***Point source:***
    Brightness ~ luminous intensity, I_v [cd]

  - ***Surface source:***
    Brightness ~ luminance, L_v [cd/m^2]

- **However, there is no standardized definition called ”brightness”**

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Photometric quantities at a glance

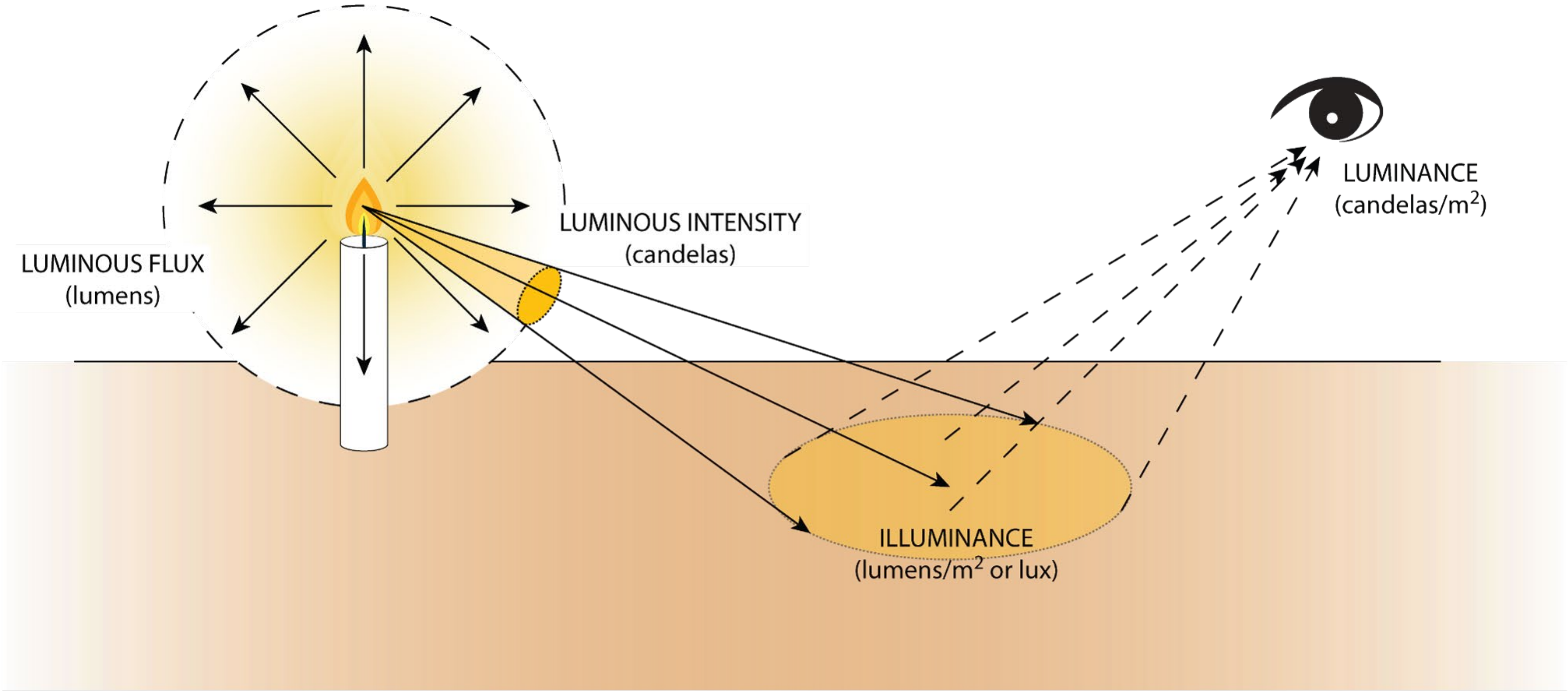
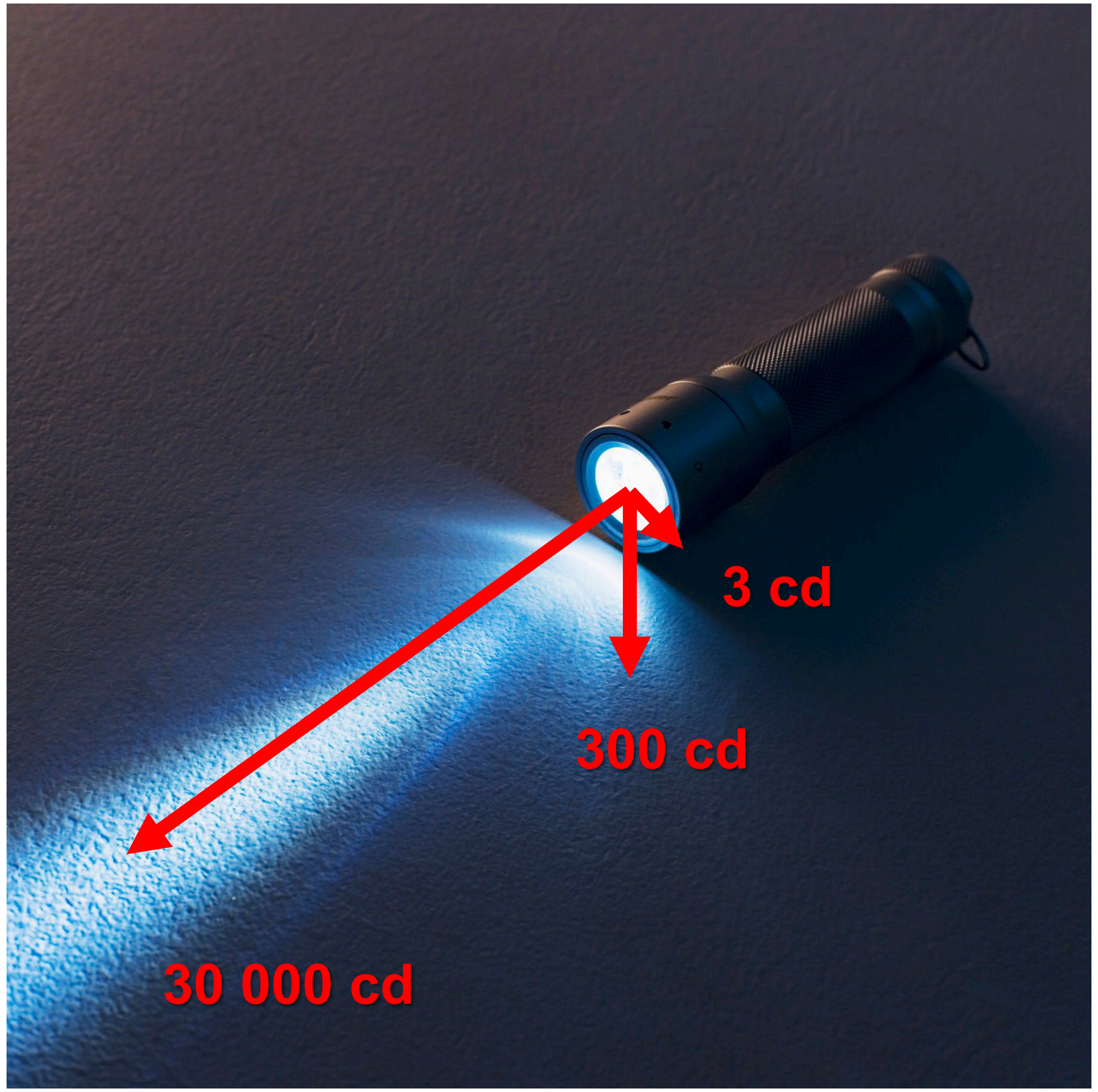
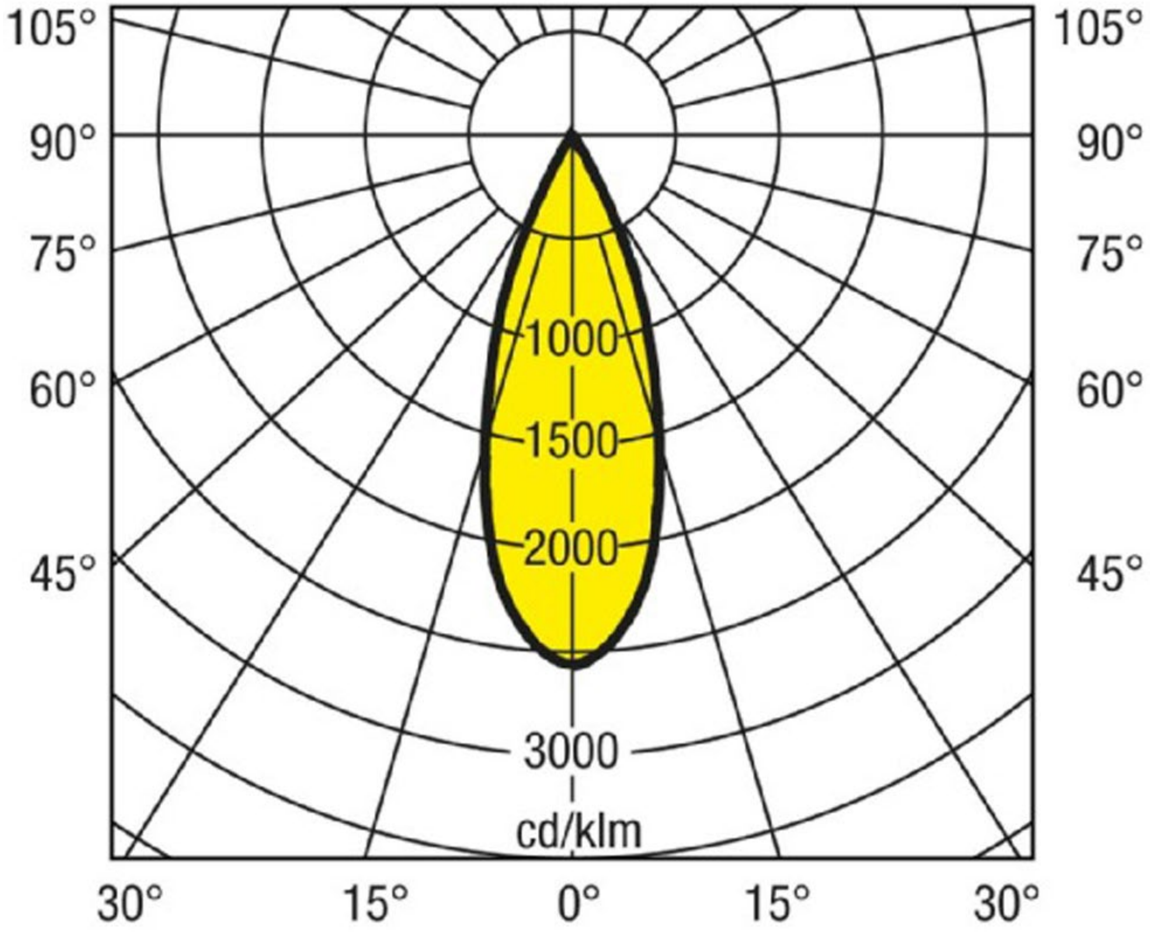


Illustration: Niko Gentile

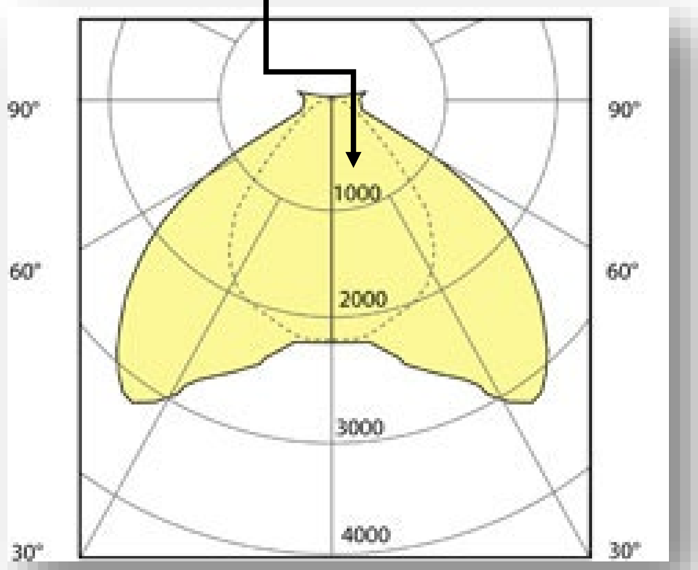

3 cd
300 cd
30 000 cd

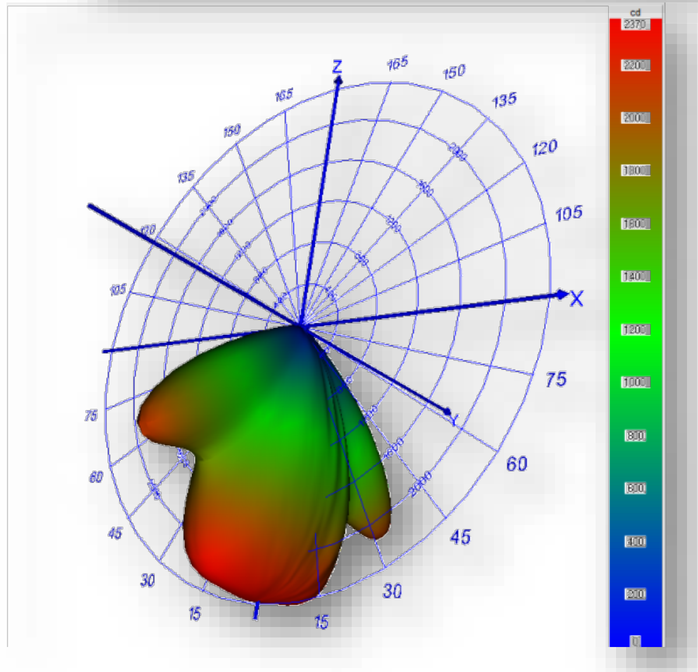

105°
90°
75°
60°
45°
105°
90°
75°
60°
45°
1000
1500
2000
3000
cd/klm
30°
15°
0°
15°
30°

Light Intensity Distribution (LID)

- Goniometer (*"gonia"* – greek. *"angle"*)
- Measures the Luminous Intensity, I_V, in different directions
- Can be visualized in planes (2D), or in space 3D

Units: cd
(sometimes cd/klm)





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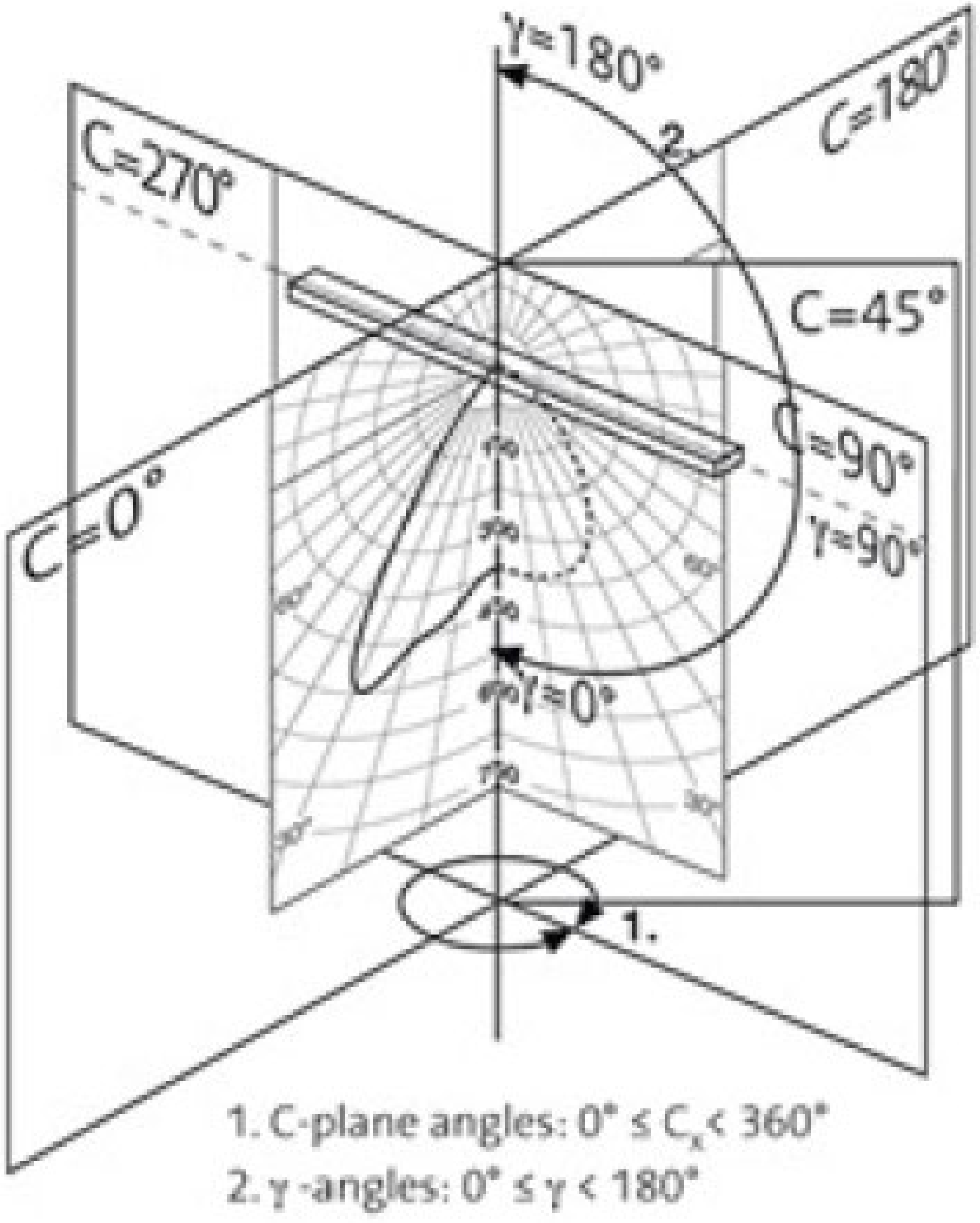
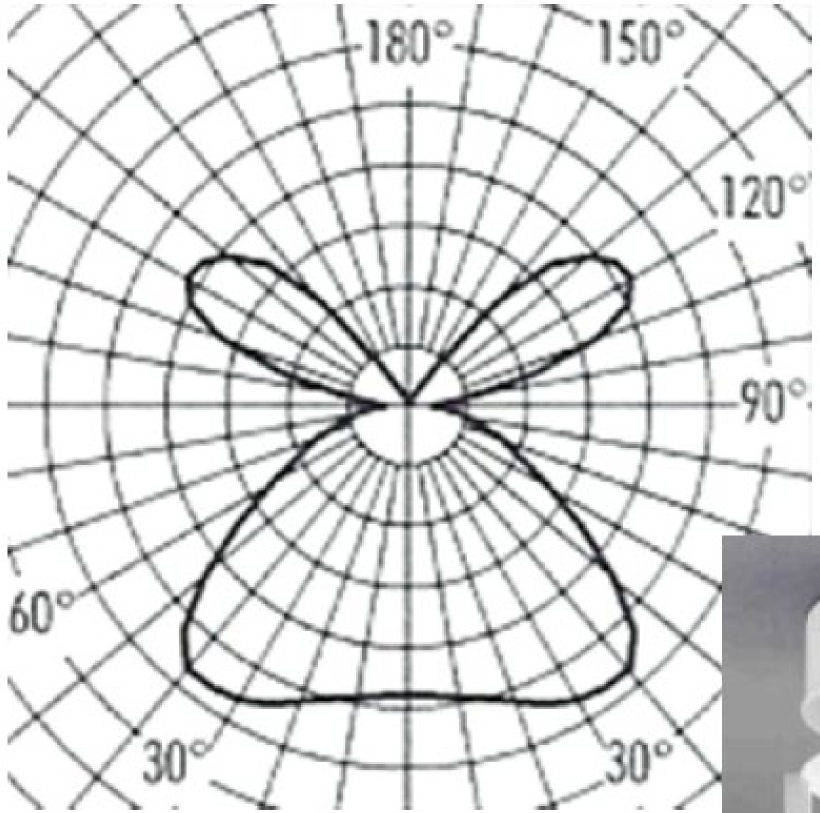


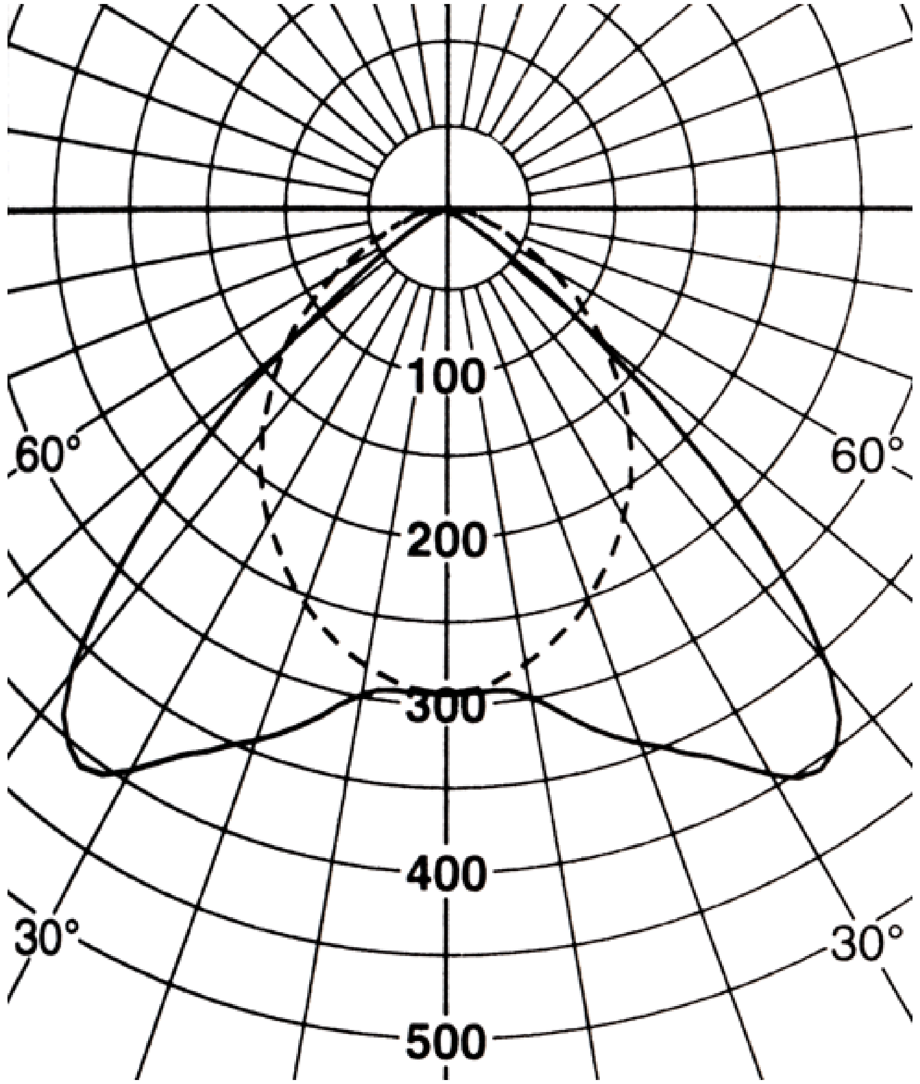
Light Intensity Distribution (LID)



Rotational symmetric distribution

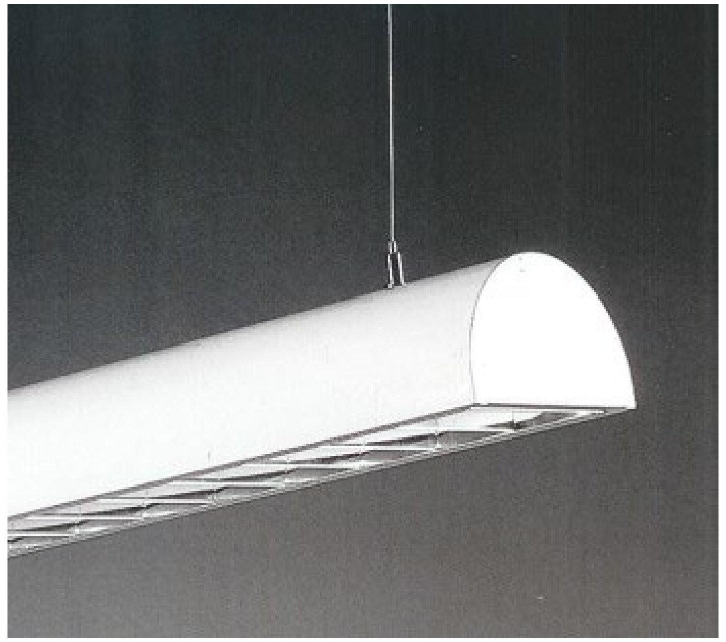
- Pendant luminaires
- Ceiling
- Spots and downlights
- Luminaires for paths and parks

Light Intensity Distribution (LID)

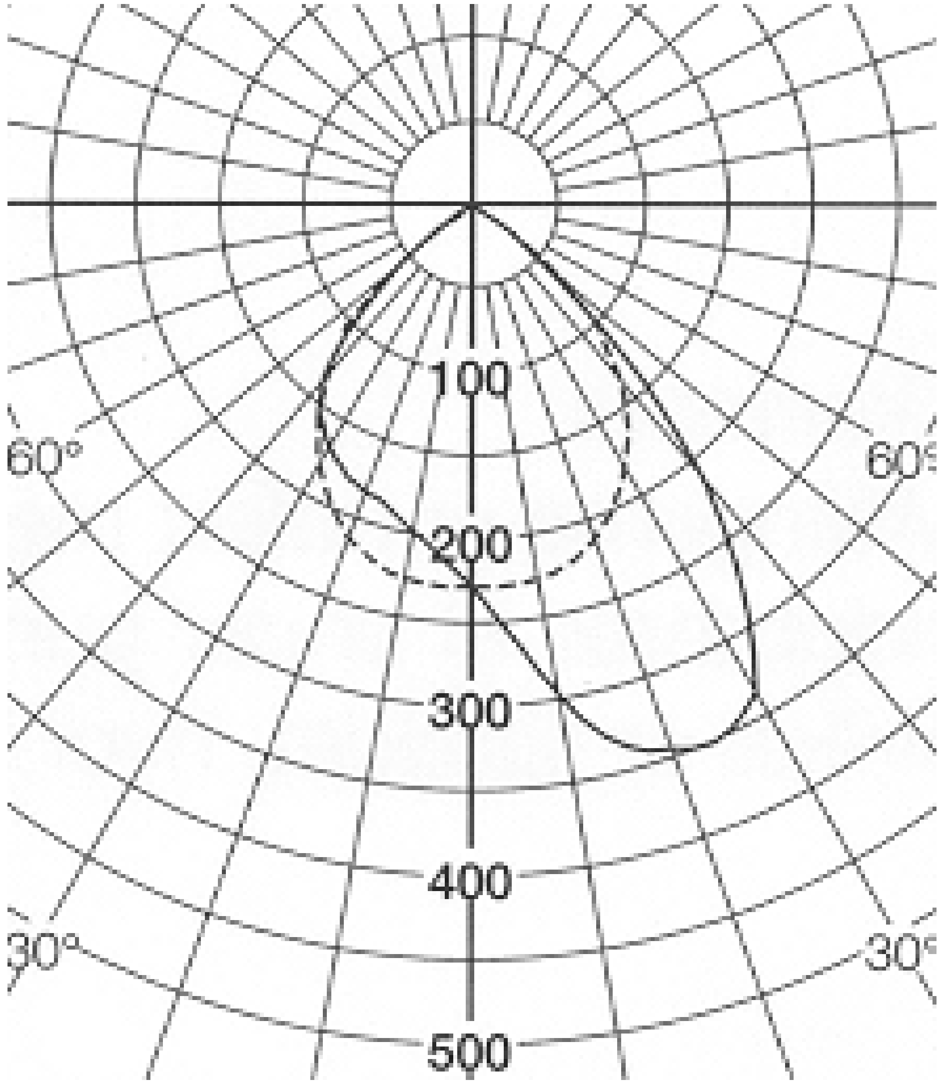


Symmetric distribution

- Symmetric in two planes
- General fluorescent tube luminaires



Light Intensity Distribution (LID)

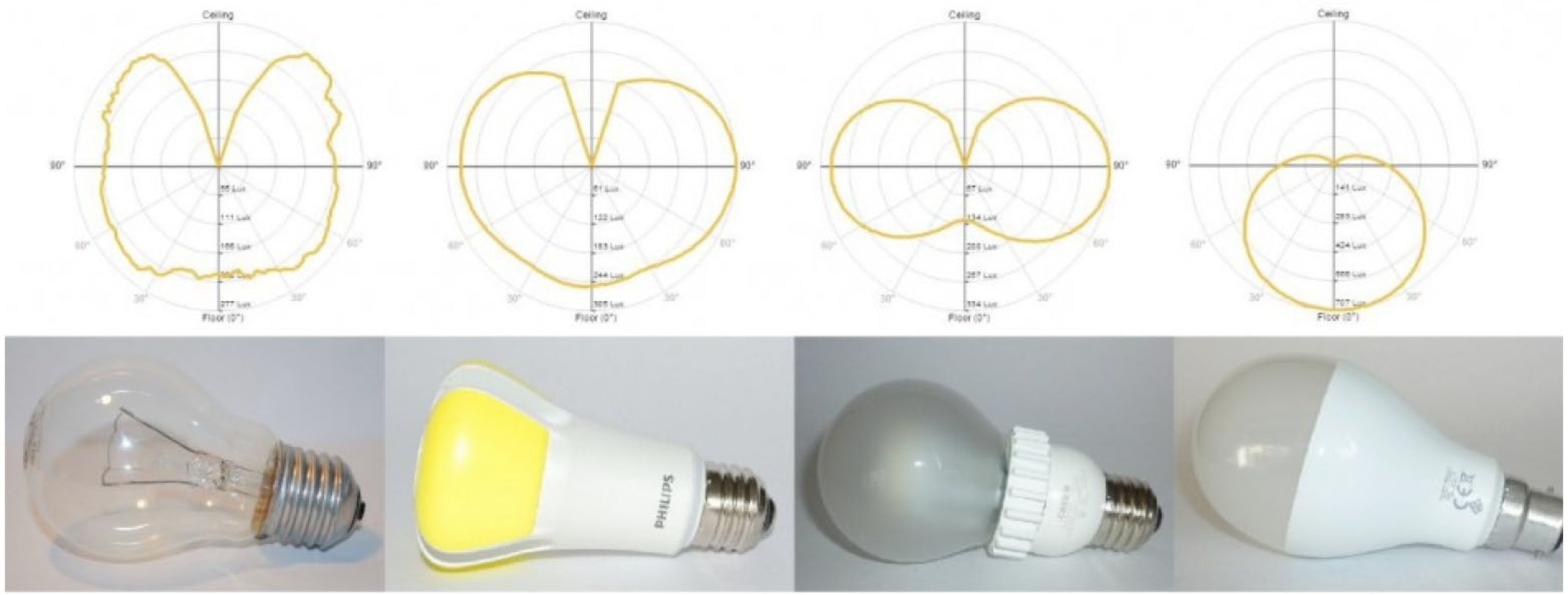


Asymmetric distribution

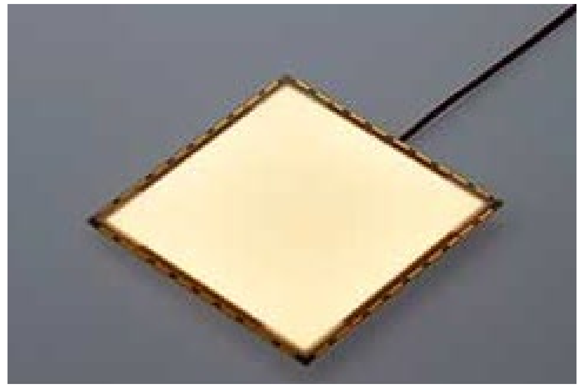
- Streetlights
- Board lights
- Shelf lights
- Work luminaires

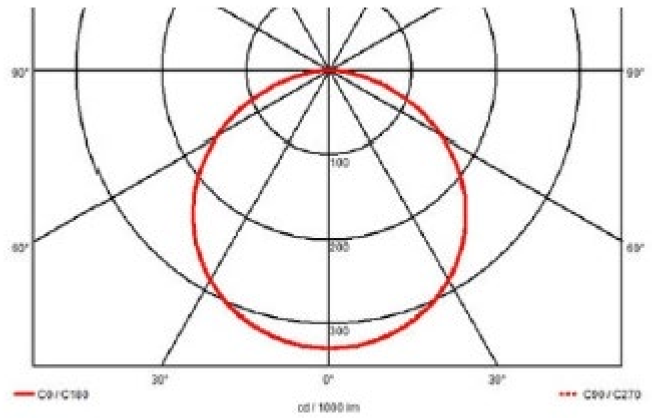
Light Intensity Distribution (LID)

Common light sources



A lambertian light source (OLED)





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Exercise

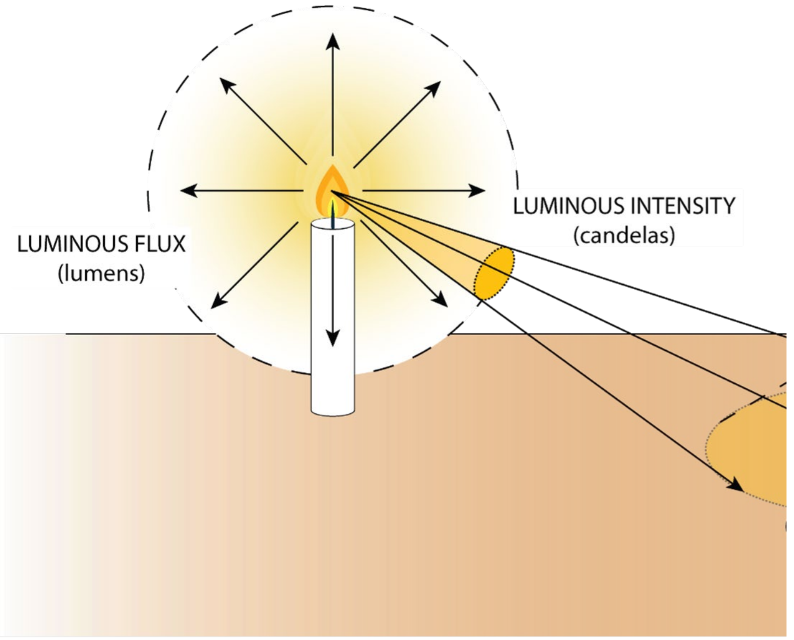
1. Calculate the luminous intensity I_v from a light source that gives the luminous flux, Φ_v, of 400 lumen, given that the light source is a

   a) ideal isotropic light sources, giving same luminous intensity in all directions
   b) flashlamp with a symmetric spreading angle of 10°.

   Remember: Solid angle ω from a symmetric angle α: $\omega = 2\pi\left(1 - \cos\left(\frac{\alpha}{2}\right)\right)$

2. Concider the flashlamp in previous problem. Calculate the illuminance produced by the light from the flashlamp on a distance of

   a) 1 meter
   b) 2 meters
   c) 4 meters



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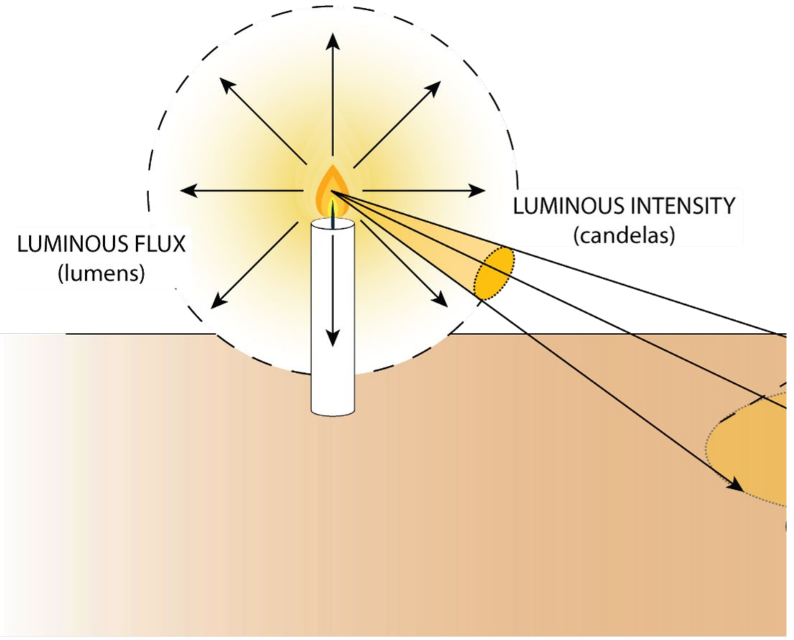

Solution to 1a:

$$\Phi_v = 400\ lm$$

$$\omega = 4\pi\ sr = 12.57\ sr$$

$$I_v = \frac{\Phi_v}{\omega} = \frac{400\ lm}{12.57\ sr} = 32\ cd$$

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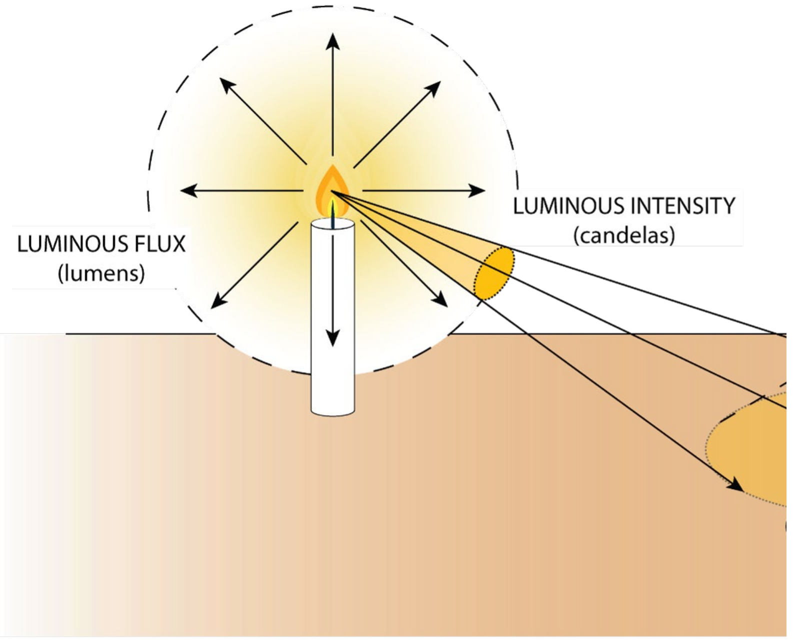
Exercise

1. Calculate the luminous intensity I_v from a light source that gives the luminous flux, Φ_v, of 400 lumen, given that the light source is a

   a) ideal isotropic light sources, giving same luminous intensity in all directions
   b) flashlamp with a symmetric spreading angle of 10°.

   Remember: Solid angle ω from a symmetric angle α: $\omega = 2\pi\left(1 - \cos\left(\frac{\alpha}{2}\right)\right)$



Solution to 1b:

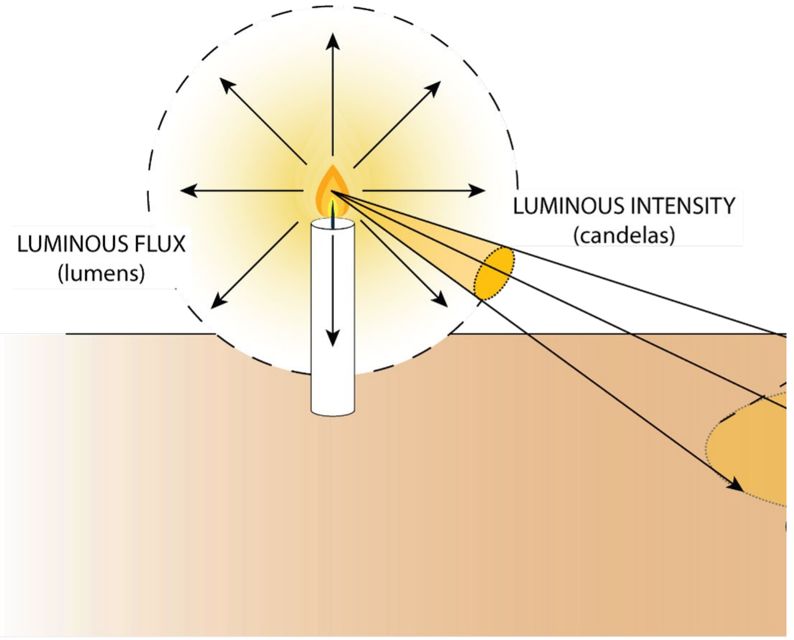
$$\Phi_v = 400\ lm\ ,\ \alpha = 10°$$

$$\omega = 2\pi\left(1 - \cos\left(\frac{10°}{2}\right)\right) = 0.024\ sr$$

$$I_v = \frac{\Phi_v}{\omega} = \frac{400\ lm}{0.024\ sr} = 17\ 000\ cd$$

Exercise

2. Concider the flashlamp in previous problem. Calculate the illuminance produced by the light from the flashlamp on a distance of
   a) 1 meter
   b) 2 meters
   c) 4 meters



Inverse Square Law: $$E_v = \frac{I_v}{r^2}$$

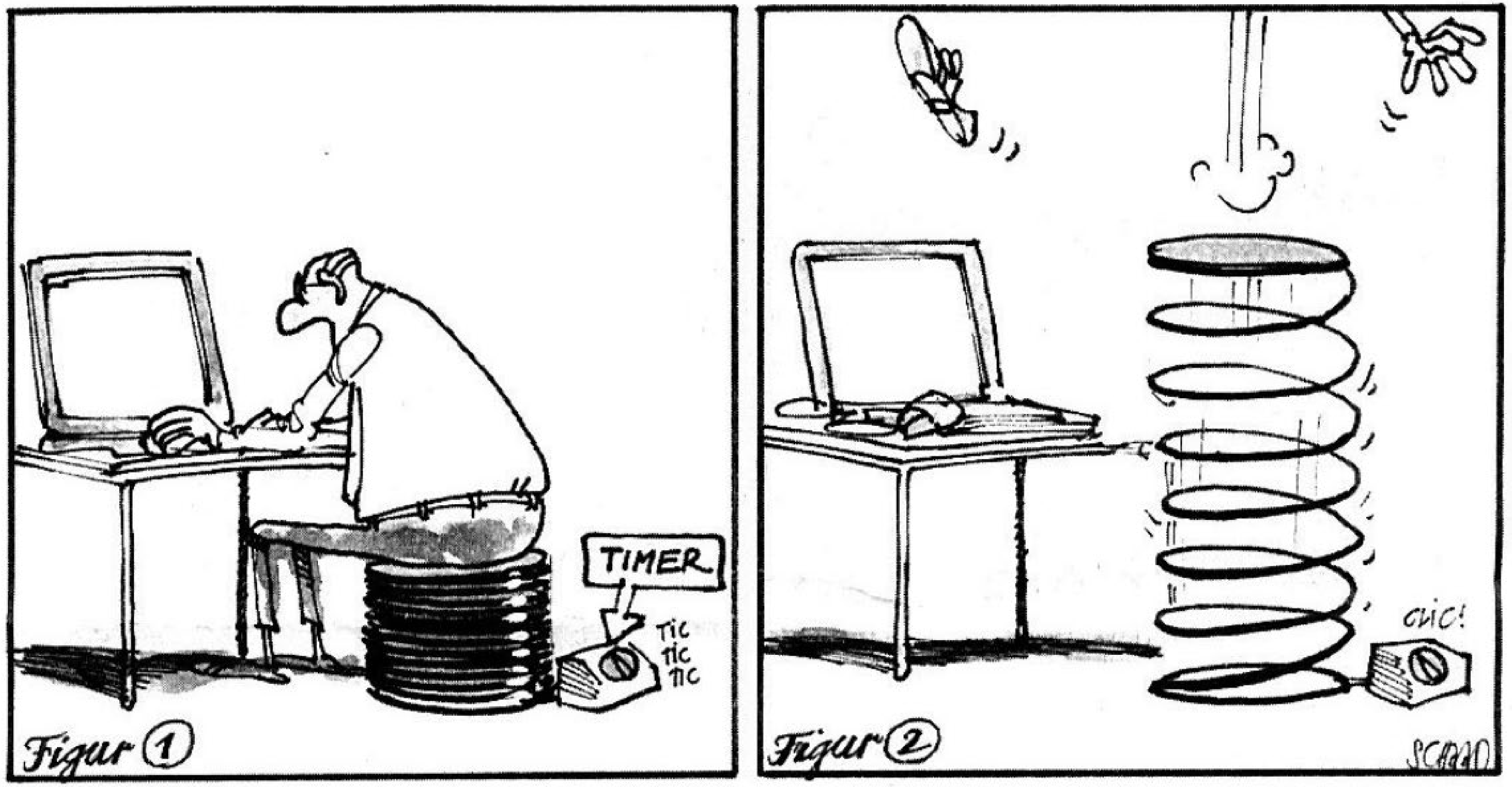
$I_v = 17\ 000\ cd$

a) $r = 1m,$ $$E_v = \frac{17\ 000}{1^2} = 17\ 000\ lx$$

b) $r = 2m,$ $$E_v = \frac{17\ 000}{2^2} = 4\ 200\ lx$$

c) $r = 4m,$ $$E_v = \frac{17\ 000}{4^2} = 1\ 050\ lx$$

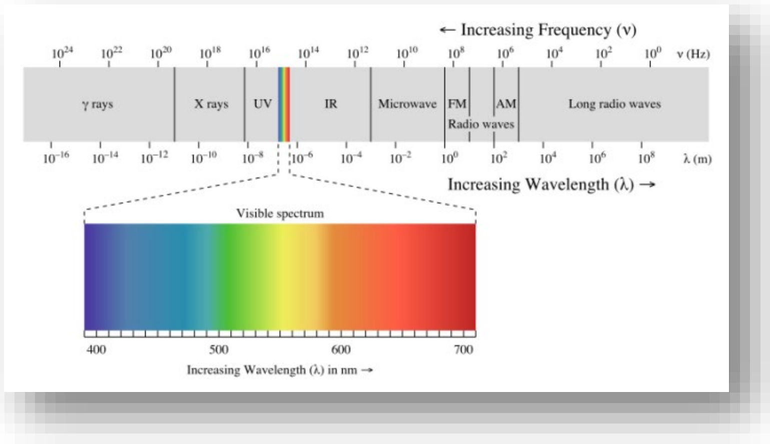
Time for a break

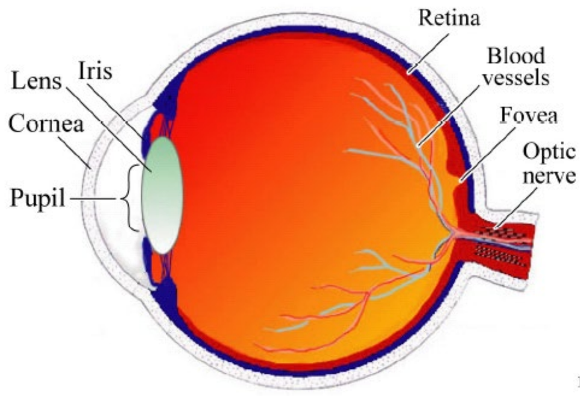


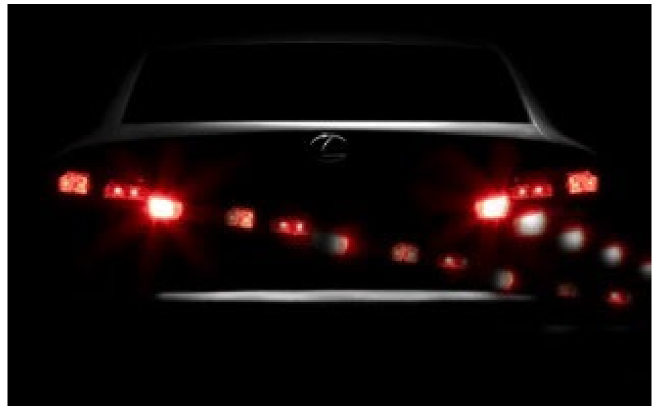
Source: *Tagesanzeiger*

Outline

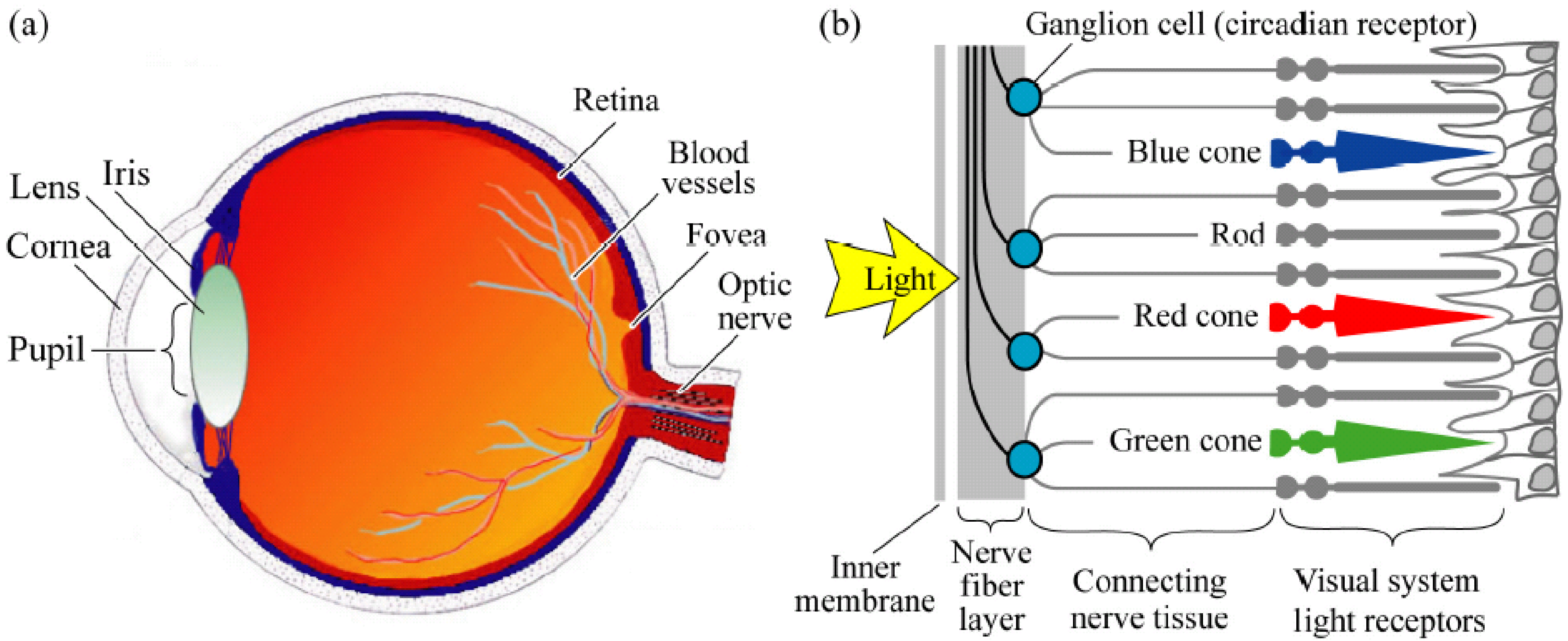
- Radiometry & Photometry
- Luminous Efficacy and ipRGC
- LED light with phosphors
- Flicker





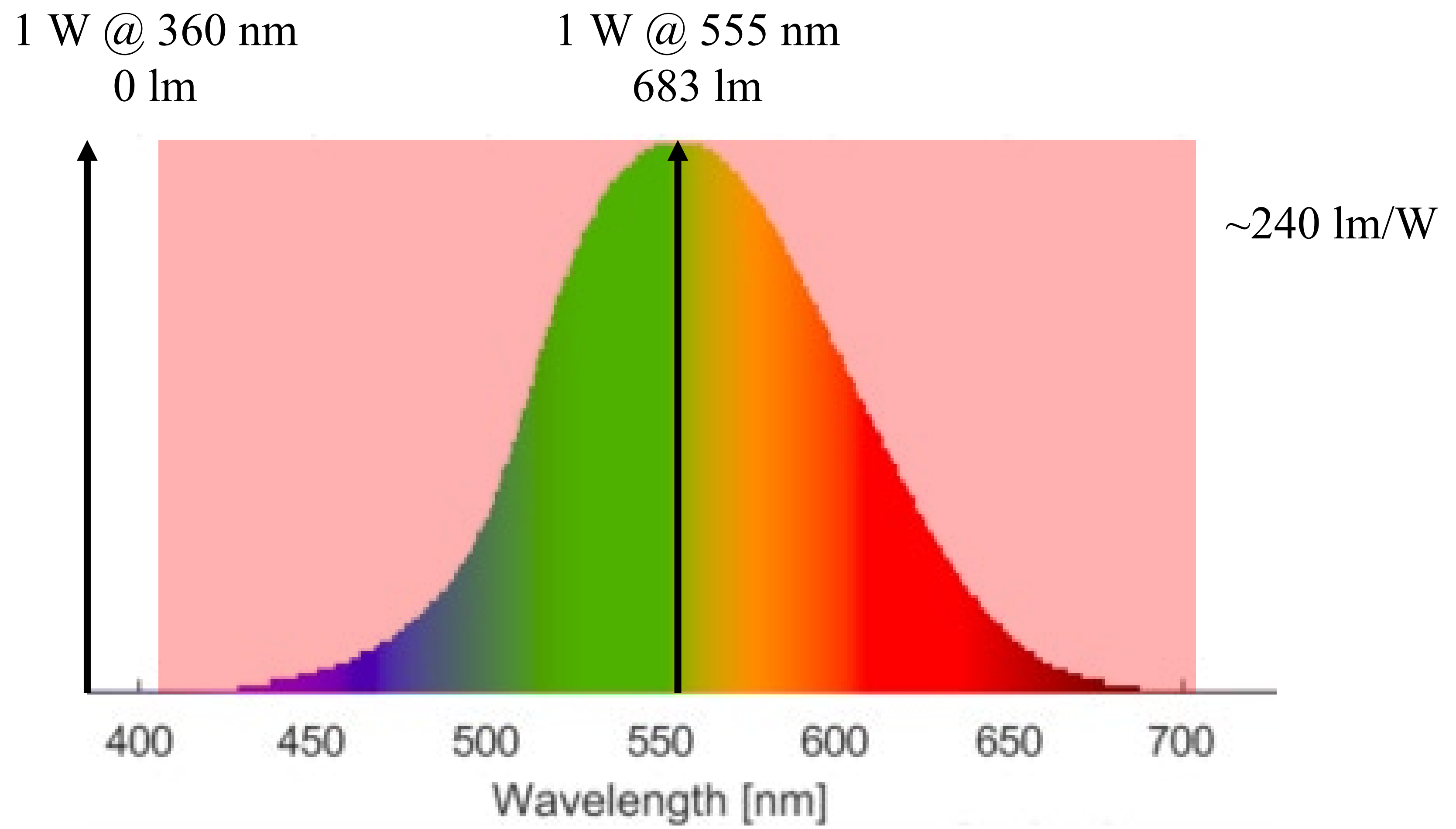


The Eye



(a)
Retina
Blood vessels
Lens
Iris
Cornea
Fovea
Optic nerve
Pupil
(b)
Ganglion cell (circadian receptor)
Blue cone
Rod
Light
Red cone
Green cone
Inner membrane
Nerve fiber layer
Connecting nerve tissue
Visual system light receptors

The Eye – Luminous efficacy



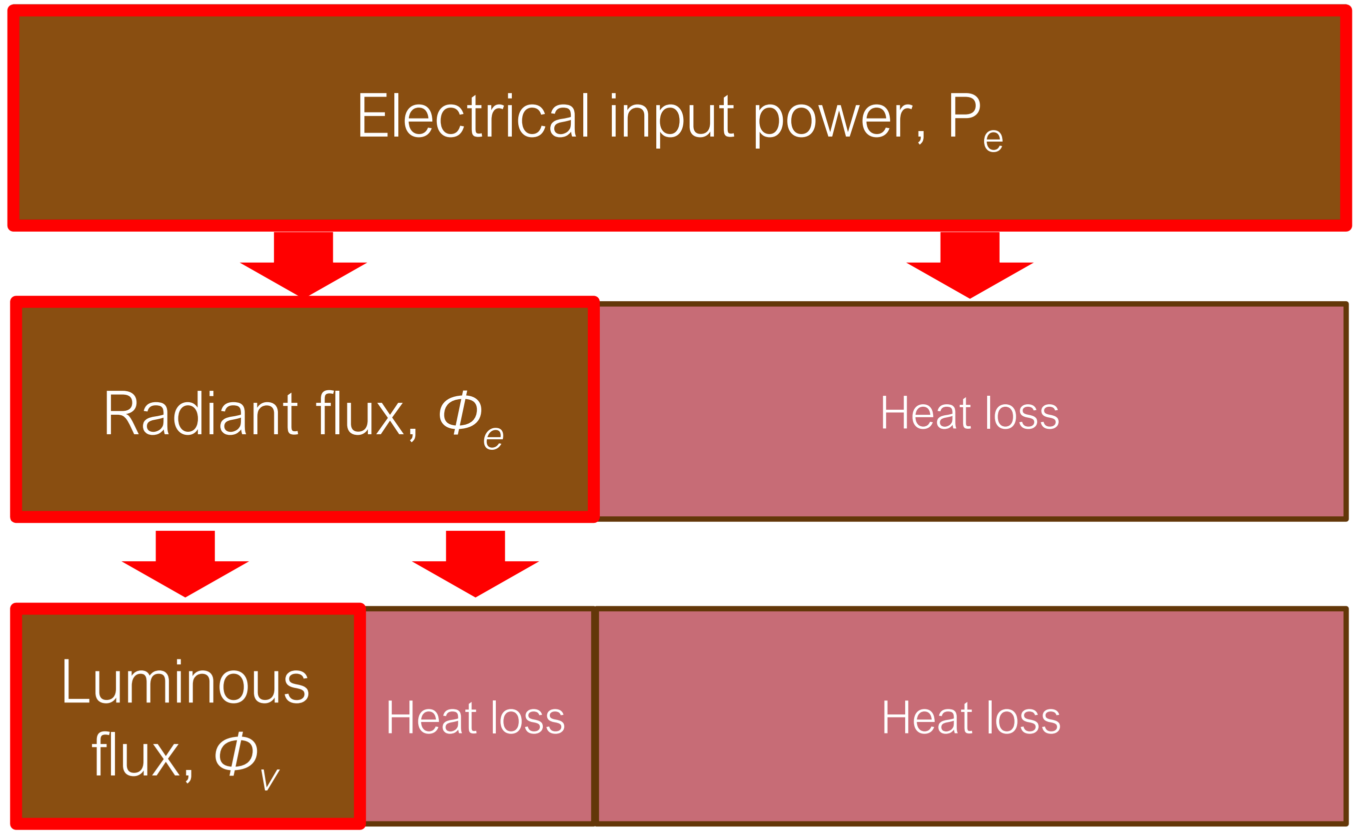
Due to definition, the maximum luminous efficacy possible is 683 lm/W

Efficiency measures of light sources

Luminous efficacy is a measure of how efficient a light source is to convert electric power into light.

Lumoinus efficacy of source, η_V, is the measure often used, and is also called wall-plug efficiency.

It's called ***efficacy*** instead of ***efficiency*** because the unit is lumen per watt [lm/W], and not unitless. Efficiency is always unitless, and often displayed in percent [%].



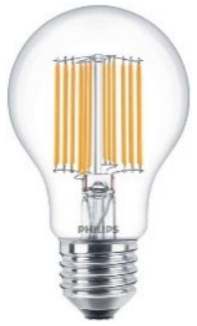
Luminous ***efficacy*** of radiation, K:

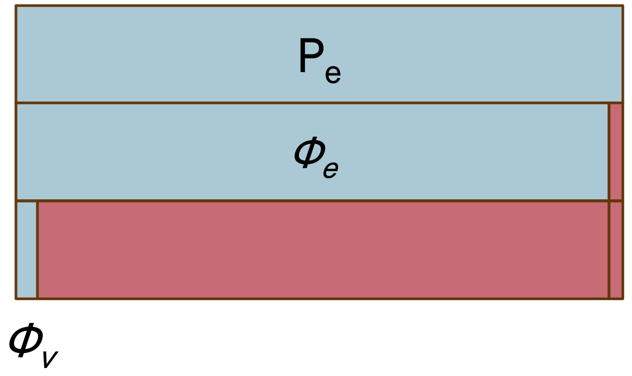
$$K = \frac{\Phi_v}{\Phi_e} \quad \left[\frac{\text{lm}}{\text{W}}\right]$$

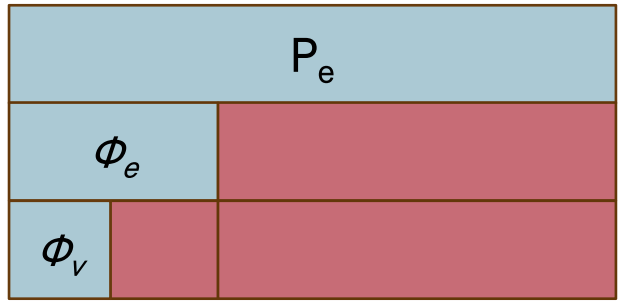
Luminous ***efficacy*** of a source, η_V:

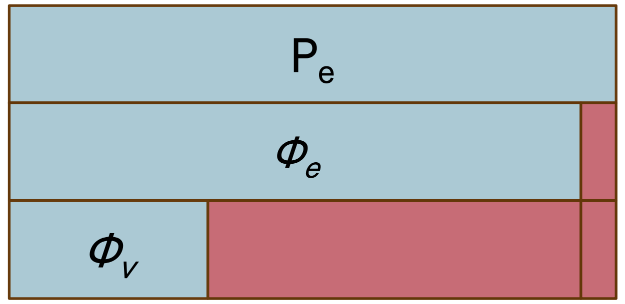
$$\eta_V = \frac{\Phi_v}{P_e} = \frac{\Phi_v}{U \cdot I} \quad \left[\frac{\text{lm}}{\text{W}}\right]$$

Efficiency measures of light sources

Incandescent	CFL (Compact Fluorescent Lamp)	Filament LED
		  Record 2017
13 lm/W	70 lm/W	190 lm/W







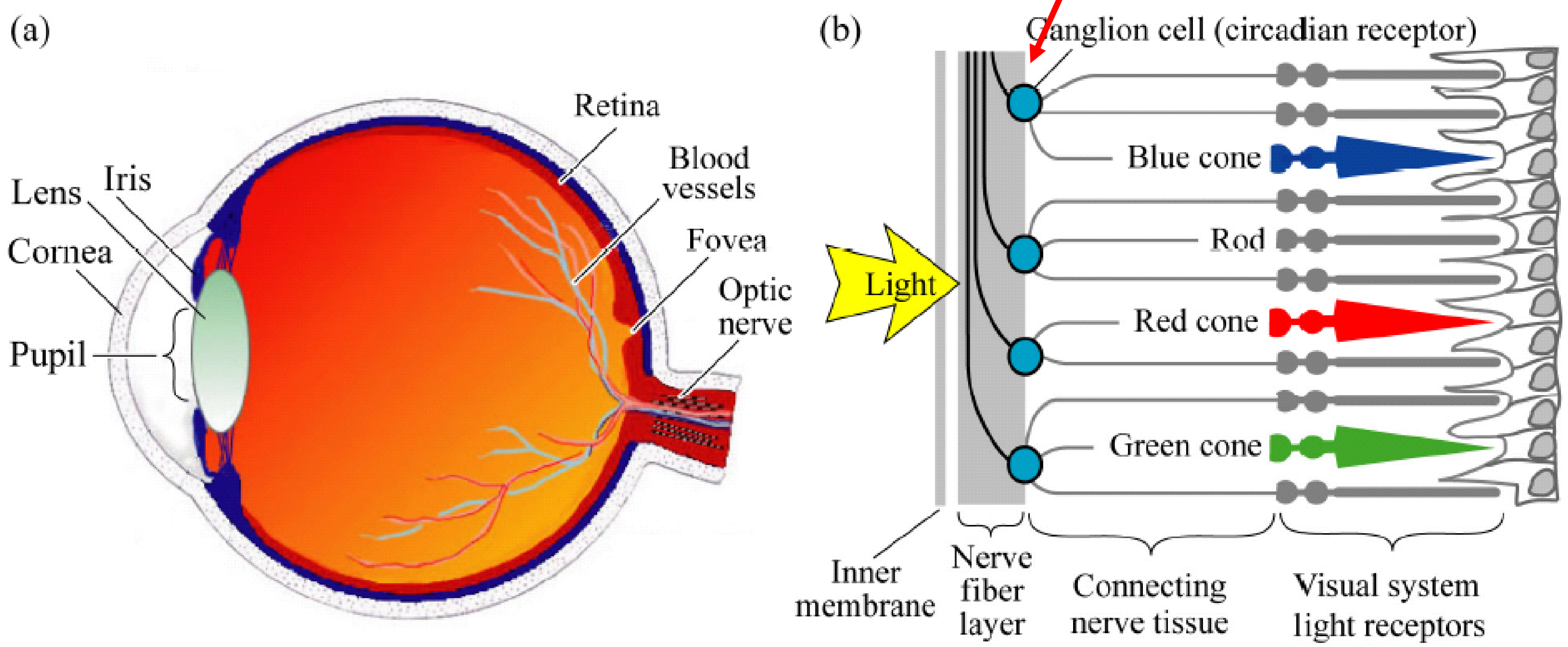
Light source	Luminous efficacy of a source (lm/W)
Incandescent bulb	10 – 15
Halogen bulb	15 – 25
CFL	50 – 80
HPS	100 – 140
Warm white LEDs	80 – 120
Cold white LEDs	120 – 190

The third receptor - ipRGC

- Two receptors on the retina of the eye
  - Cones – for color vision
  - Rods – for low light level vision

  But there's a third receptor...

The intrinsically photosensitive Retinal Ganglion Cells (ipRGC) discovered to be sensitive to light in 2002.



- Sensitivity peak at 484 nm (blue)
- Synchronize the human circadian rhythm
- Suppress melatonin production when exposed to light

Berson, D. M. et al (2002). Phototransduction by Retinal Ganglion Cells That Set the Circadian Clock. *Science*, *295* (5557)

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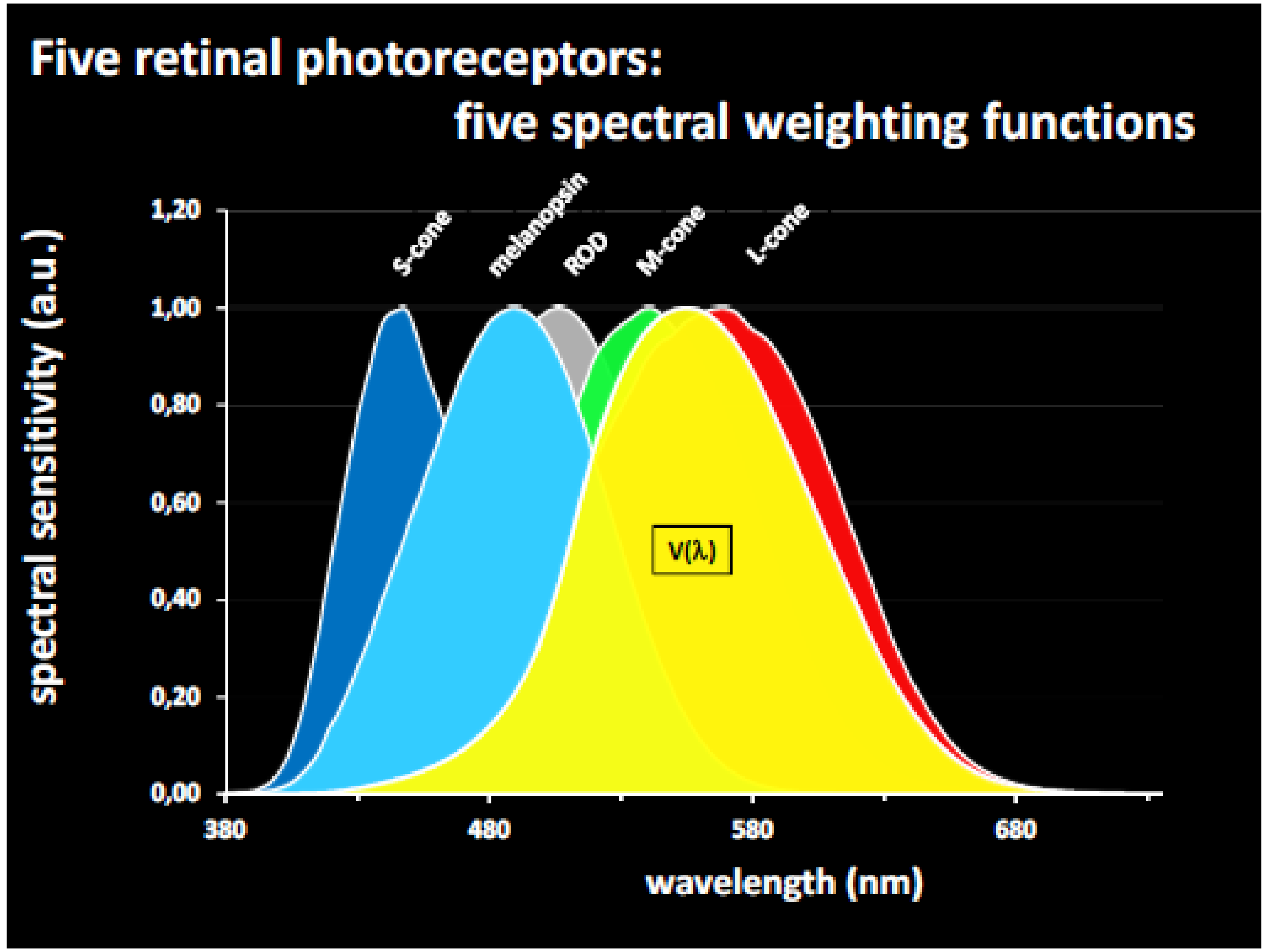
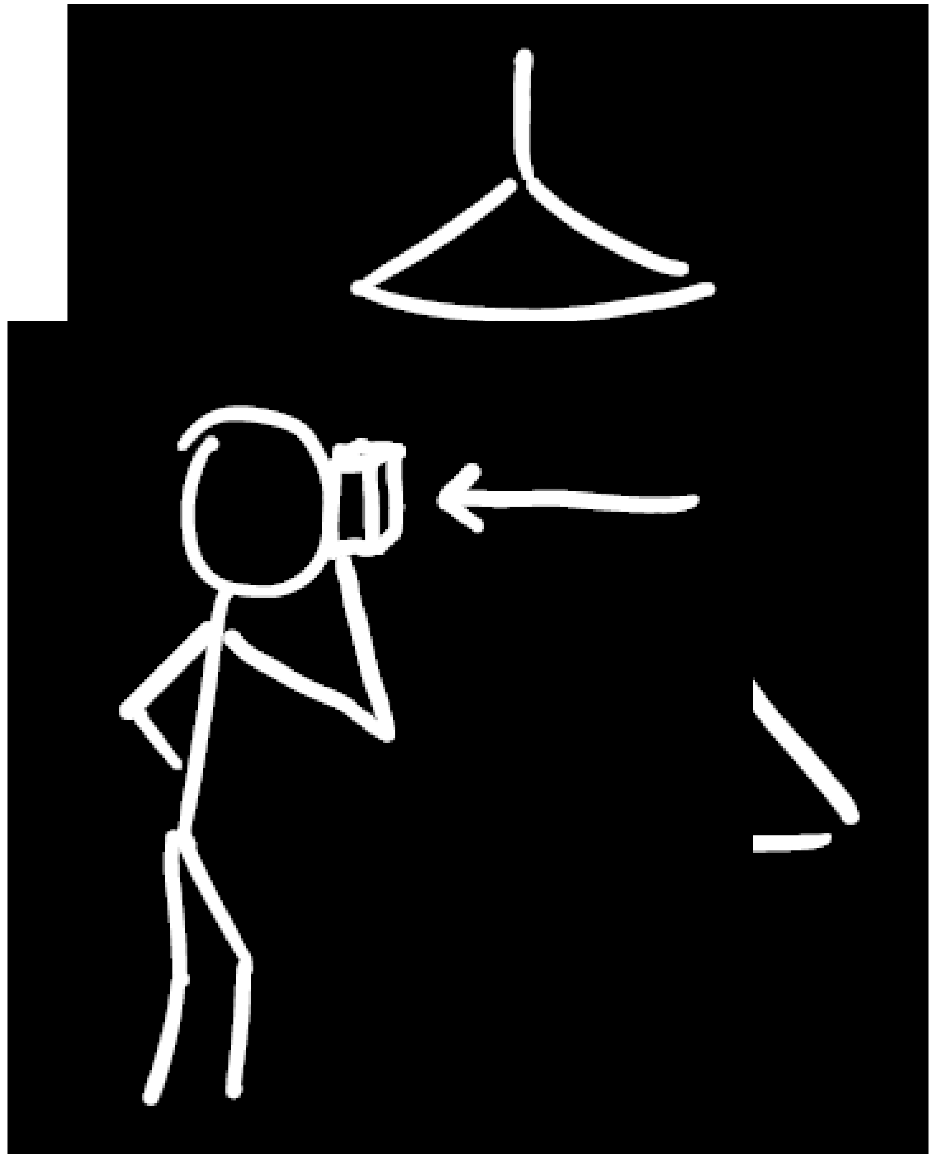
Circadian lighting

- CIE S 026/E:2018 – "CIE System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light"
- α-opic radiation
- Melanopic radiation
- Melanopic equivalent daylight illuminance, mEDI
- Melanopic daylight efficacy ratio, mDER



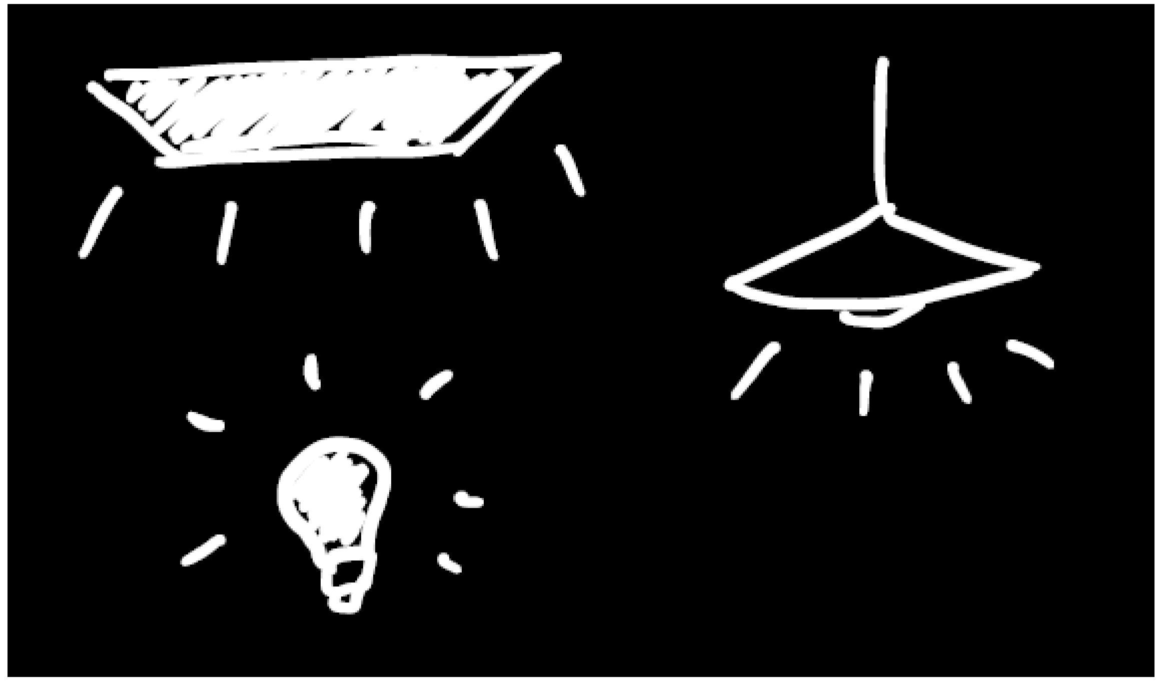
Melanopic equivalent daylight illuminance - mEDI

- Daylight (D65) – standardized daylight at 6500 K
- Abbreviation: mEDI (not standard)
- Symbol: $E_{v,mel}^{D65}$
- Unit: lux
- Description:
  The measured value mEDI $E_{v,mel}^{D65}$ from a test light source is the irradiance (lux) you need from daylight to achieve the same amount of melanopic stimuli from daylight as from the test light source



Melanopic daylight efficacy ratio - mDER

- Daylight (D65) – standardized daylight at 6500 K
- Abbreviation : mDER (sometimes the same as Melanopic/Photopic-ratio)
- Symbol: $\gamma_{v,mel}^{D65}$
- Unitless
- Description:
  The mDER-value of a light source is used to compare its ability to melanopic stimuli compared to daylight.
  $\gamma_{v,mel}^{D65} = 1$ means the same stimuli as daylight.



Outline

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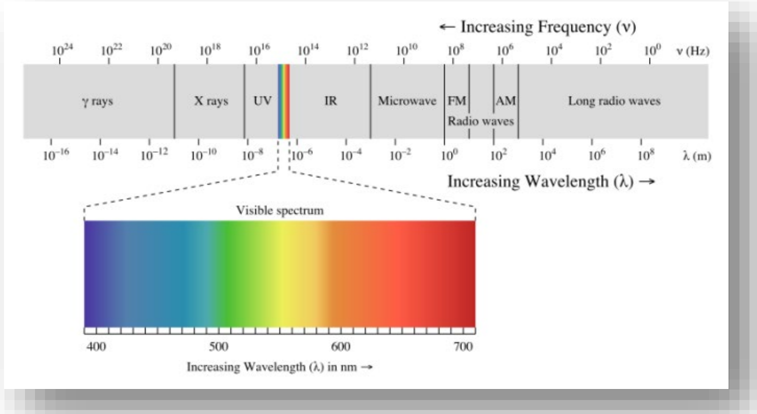
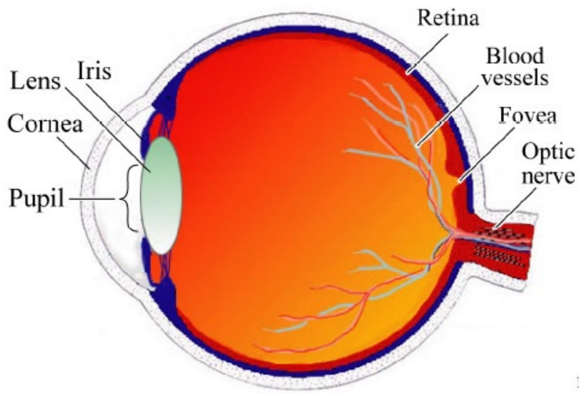
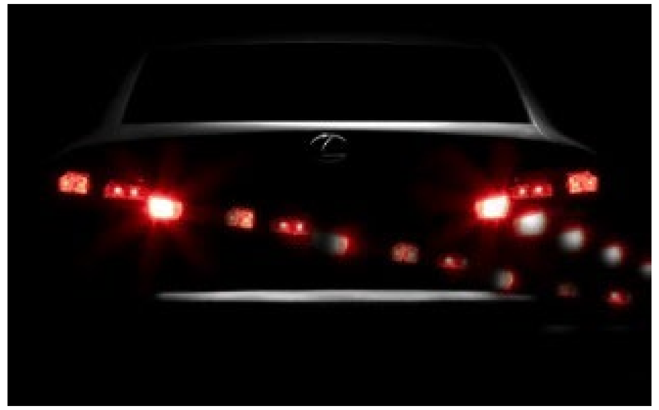
- Luminous Efficacy and ipRGC
- LED light with phosphors
- Flicker





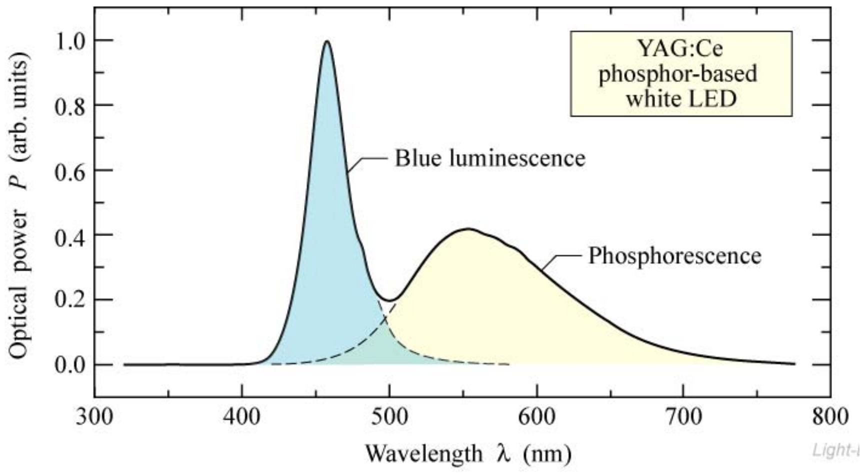


White light from LEDs – in two ways

1) Mixing of colored LEDs (RGB)

2) Phosphor convertion

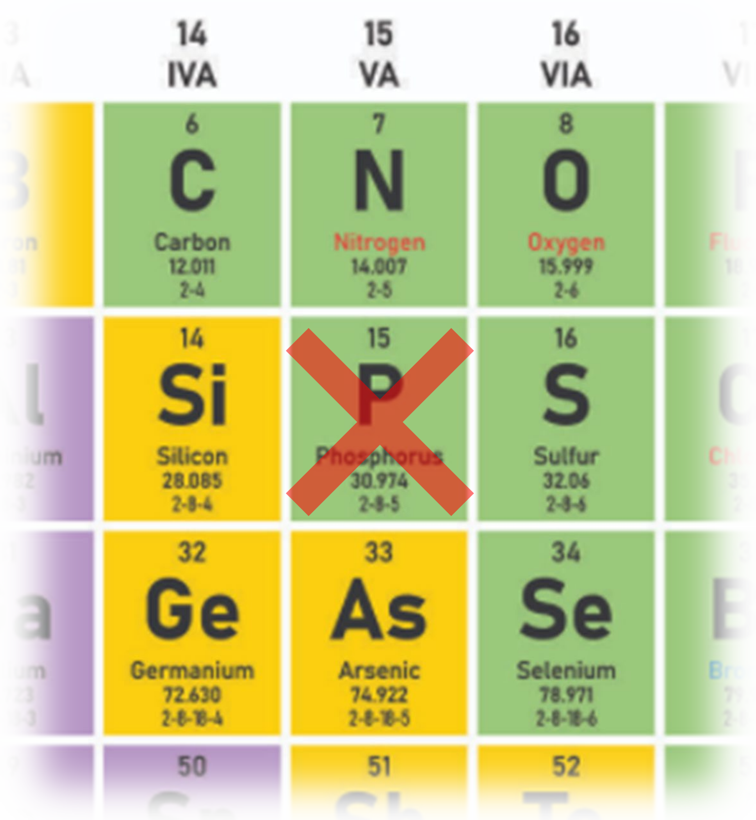
A blue LED exciting a phosphorescent material



White light using phosphors

First some clarifications:

Phosphor is not the same as the element phosphorous.



Phosphor

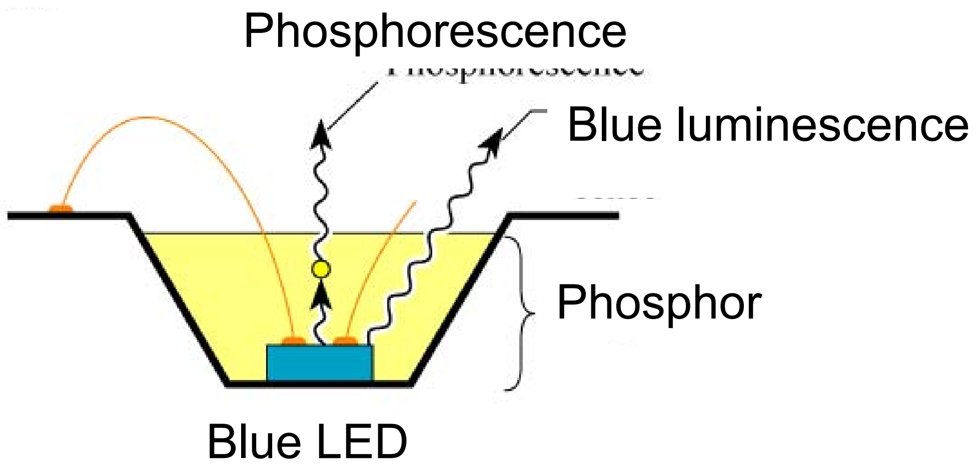
- is a solid luminescent material or inorganic powder synthesized for purpose of practical application
- is an inorganic host doped with an optically active element:
  - Ce-doped garnets: (YAG:Ce, LuAG:Ce, TbAG:Ce, GdYAG:Ce $(Y_{1-x}Gd_x)_3(Al_{1-y}Ga_y)_5O_{12}$:Ce, …)
  - Eu-doped nitrides: ($CaAlSiN_3$:Eu, β-SiAlON:Eu, $Ca_2Si_5N_8$:Eu, …)
- emits light after exposure of UV or near-UV light

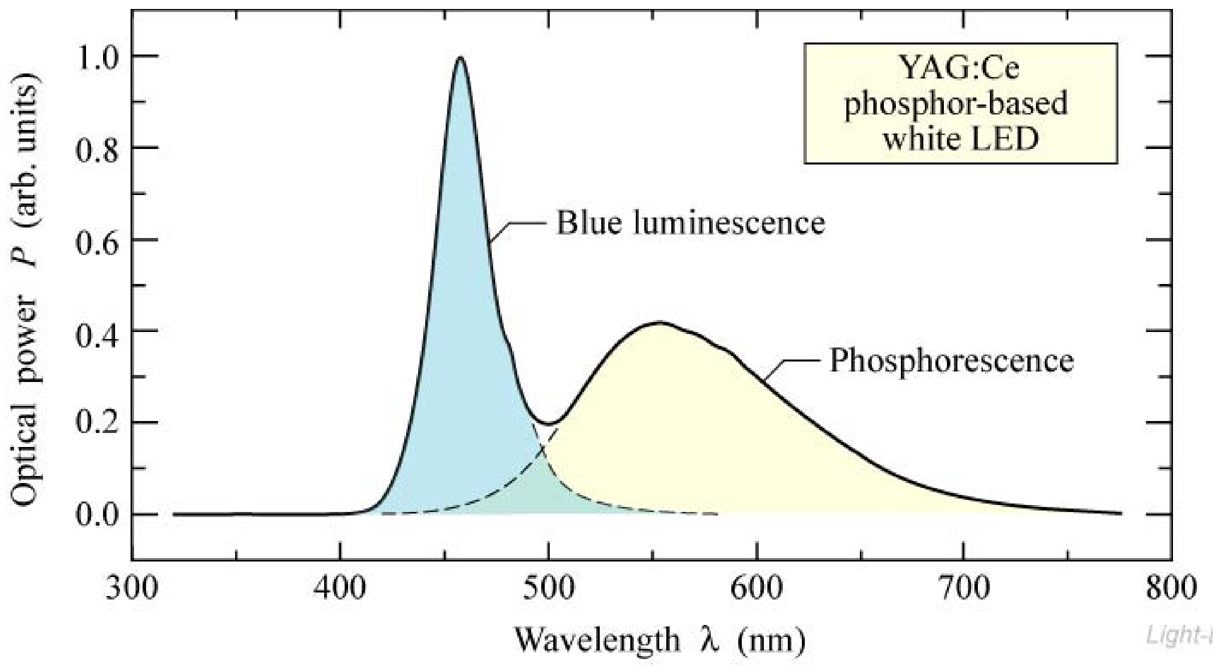
Since the element phosphorous is called “fosfor” in Swedish there’s a risk of misunderstanding.

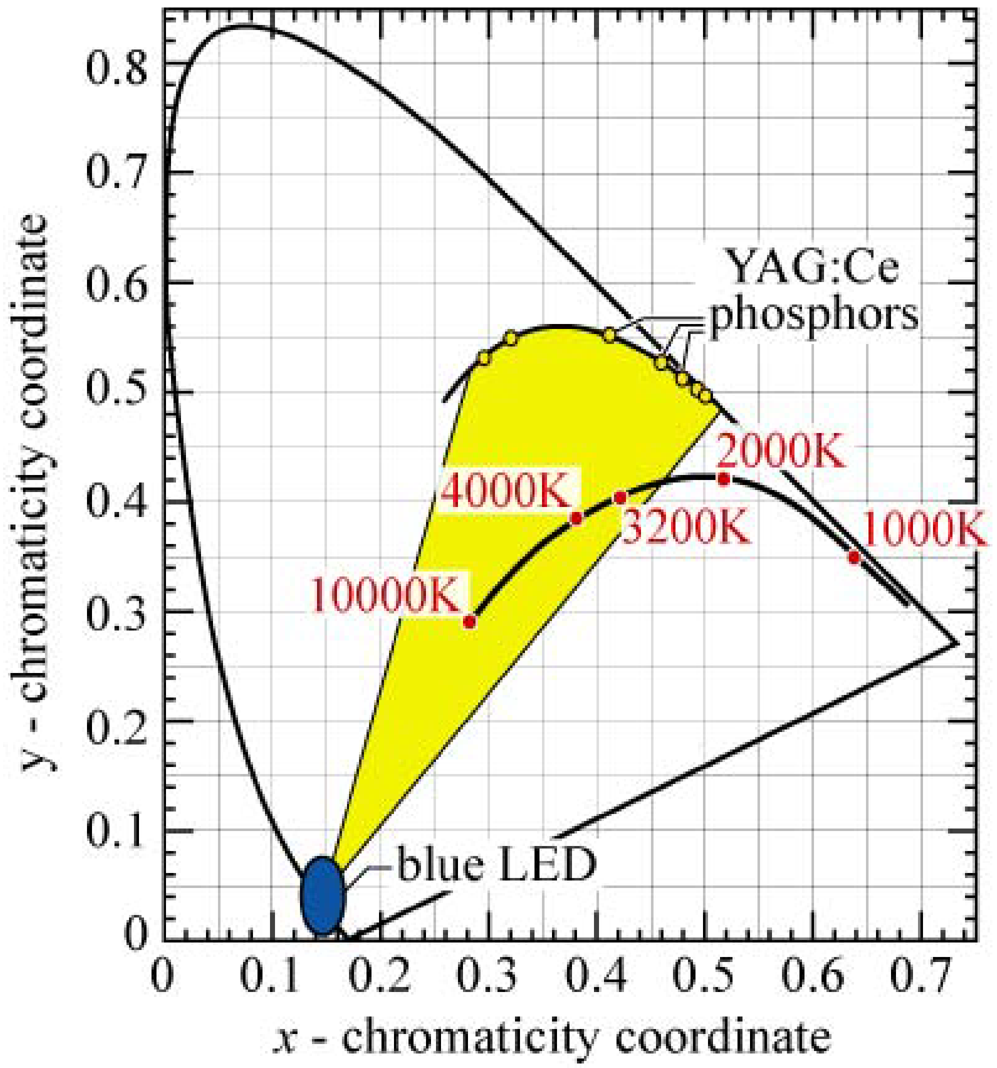
A preferred word in Swedish would be “lysämne”.

White light using phosphor convertion

Blue LED coated with a phosphor, which absorps blue light
and emits light at longer wavelengths







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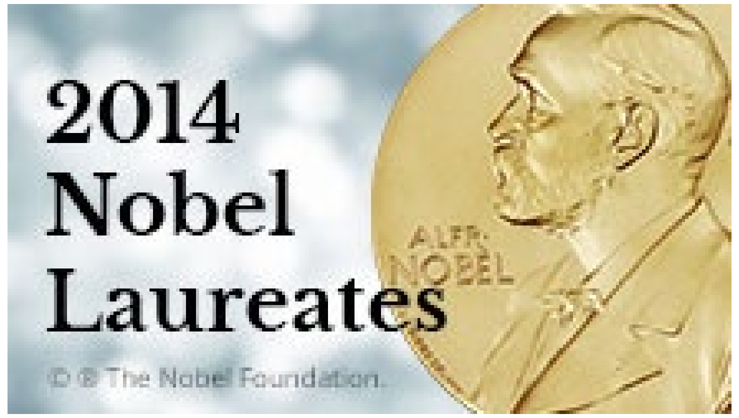
White LED light – Phosphors

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES



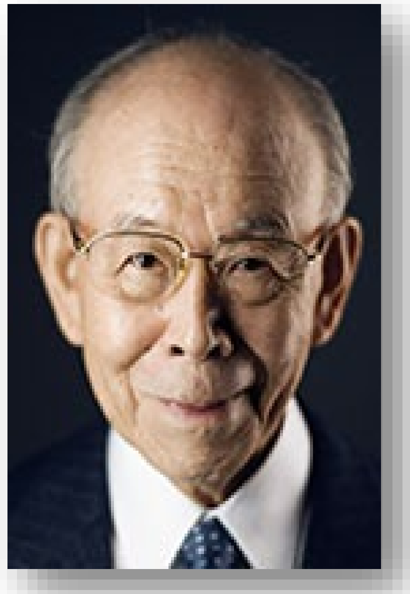
Press Release 7 October 2014

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2014 to

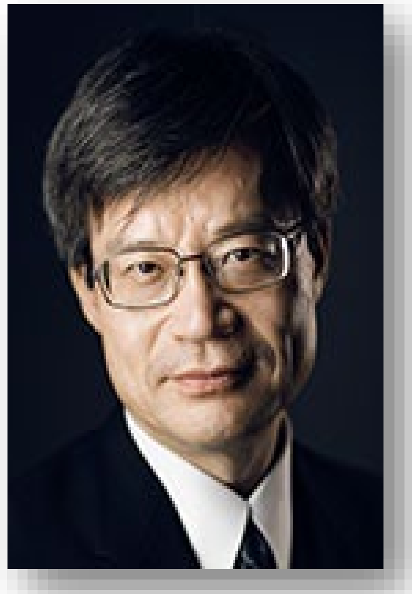
Isamu Akasaki
Meijo University, Japan
Hiroshi Amano
Nagoya University, Japan
and
Shuji Nakamura
University of California, Santa Barbara, CA, USA

“for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources"

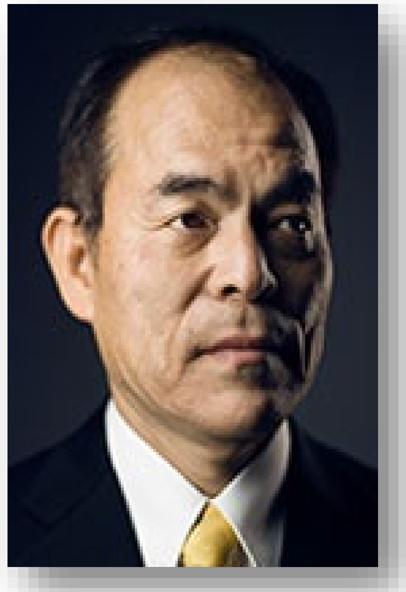
Isamu Akasaki



Hiroshi Amano



Shuji Nakamura



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White LED light - Phosphors

Phosphor coating placement:

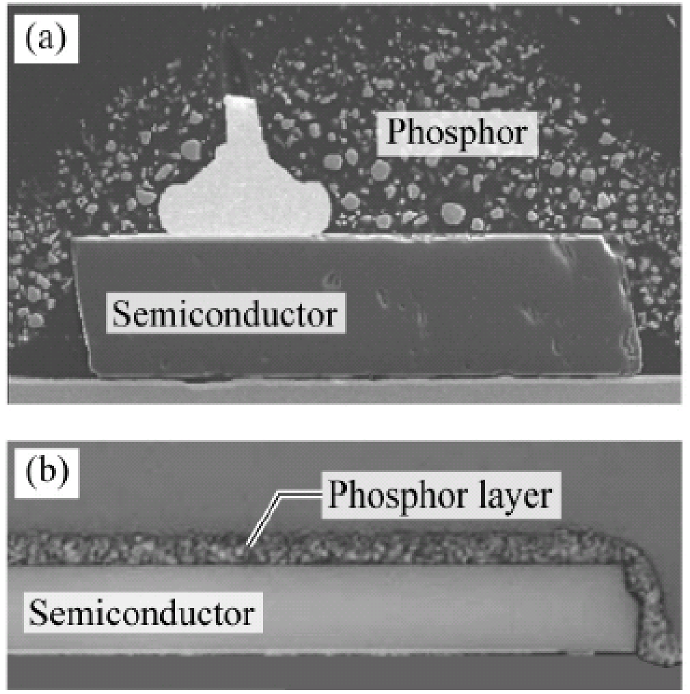
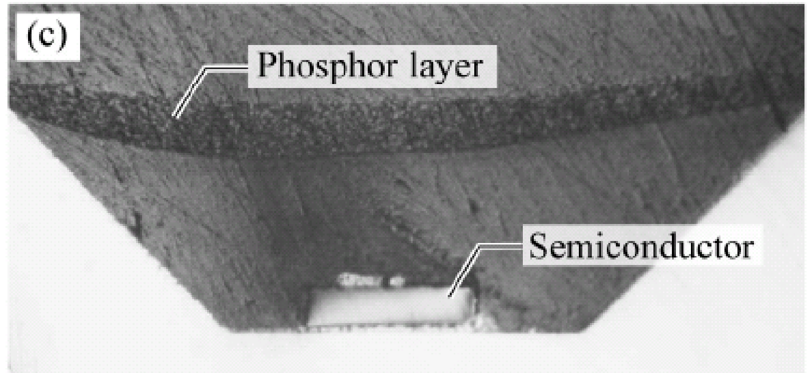
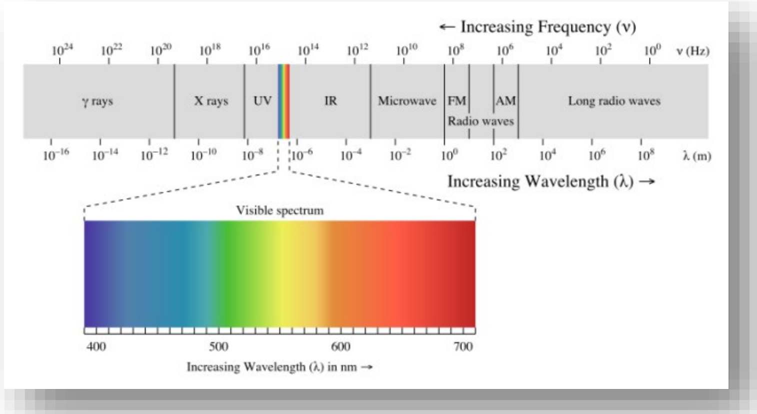


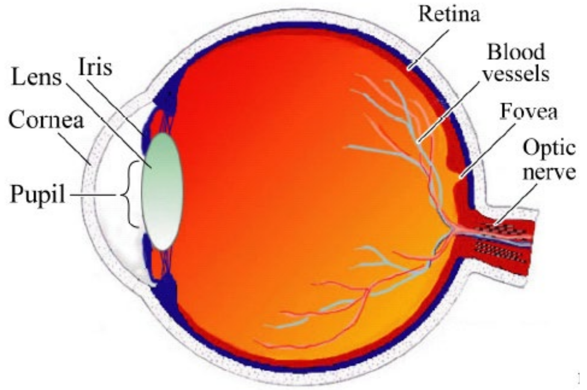
Fig. 21.11. Phosphor distributions in white LEDs: (a) Proximate phosphor distribution. (b) Proximate conformal phosphor distribution. (c) Remote phosphor distribution ((a) and (b) adopted from Goetz, 2003; (c) after Kim *et al.*, 2005).

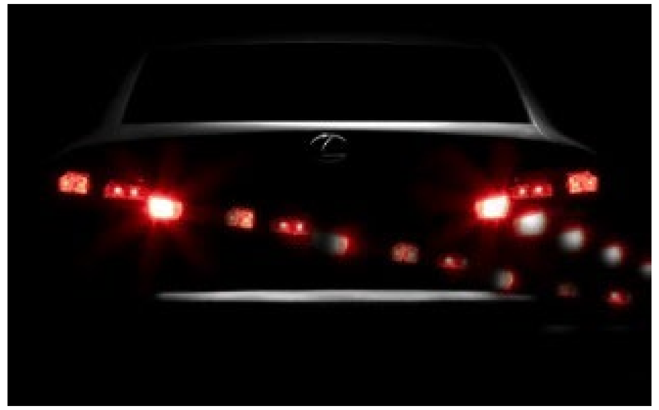


Outline

- Radiometry & Photometry
- Luminous Efficacy and ipRGC
- LED light with phosphors
- Flicker







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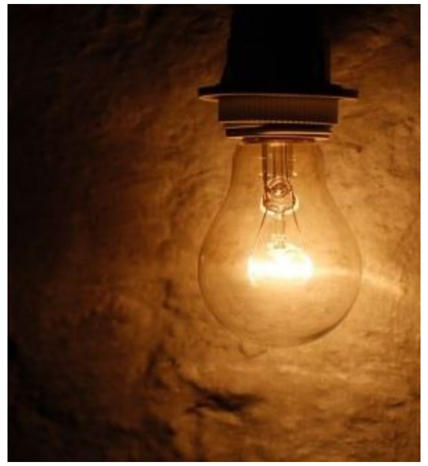
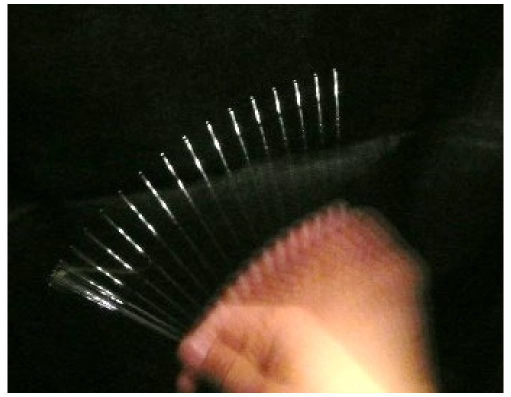
Temporal light artefact – “Flicker”

- **Flicker (P_{st}^{LM})** (< 80 Hz)
  perception of visual unsteadiness induced by light that fluctuates with time, for a
  static observer in a
  static environment



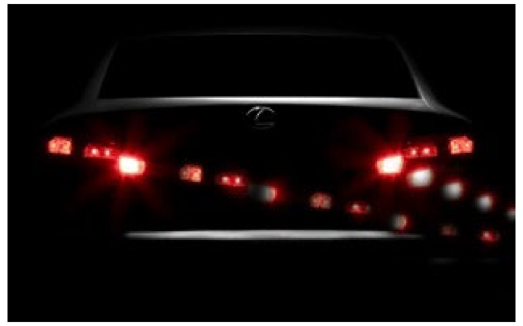
Eyes and light source ”steady”

- **Stroboscopic effect (SVM)** (80 Hz – 2000 Hz)
  change in motion perception induced by light that fluctuates with time, for a
  static observer in a
  non-static environment



Light source or object in light moving

- **Phantom array effect (ghosting)** (80 Hz – 11kHz)
  change in perceived shape or spatial positions of objects, induced by light that fluctuates with time, for a
  non-static observer in a
  static environment



Eyes moving

The effect above is called Temporal Light Artifacts (TLA).
TLAs are caused by Temporal Light Modulation (TLM)

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What is flicker?

- Strictly speaking…
- Flicker is not something light or a lamp ***does***, it's something ***you see***.
- Flicker is a special case of
  Temporal Light Artefacts (TLA)
- TLAs are caused by
  Temporal Light Modulation (TLM)

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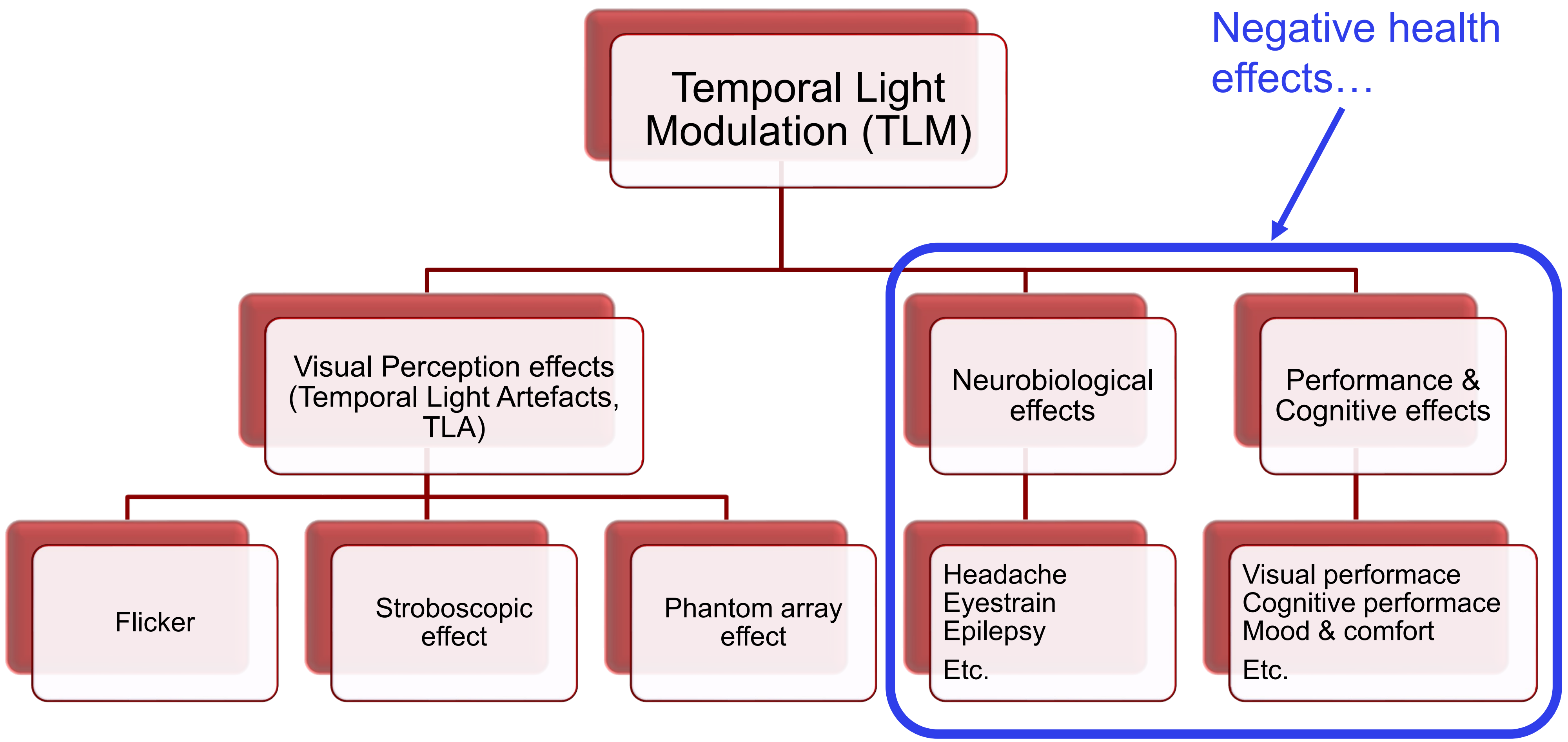
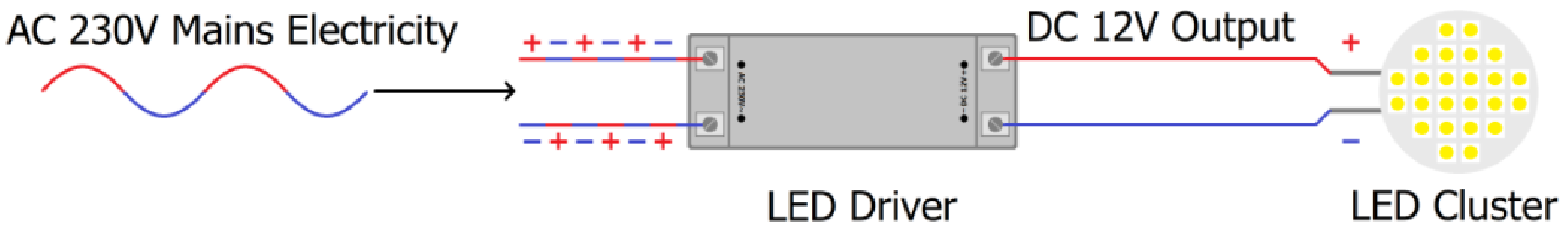
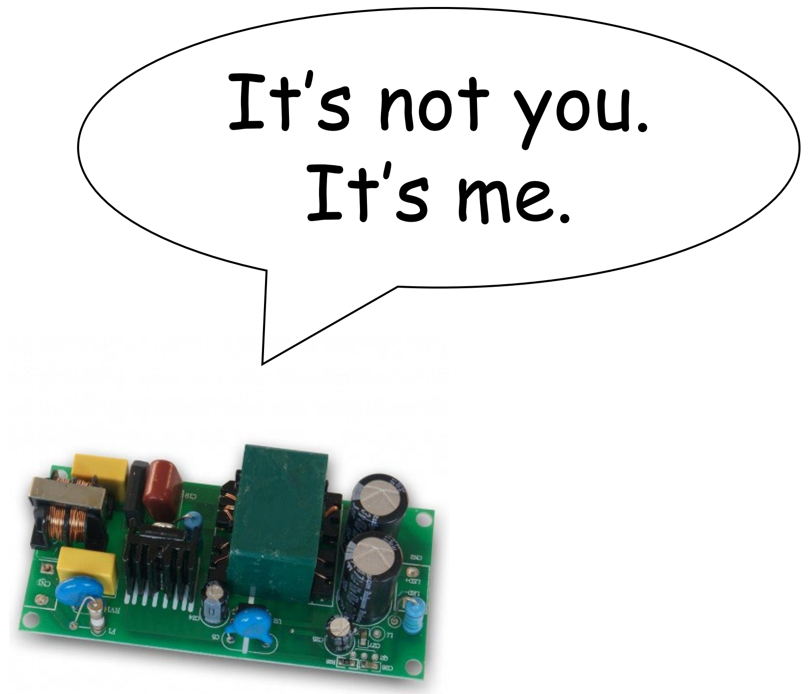
Temporal Light Modulation (TLM)



LEDs do not ~~flicker~~ modulate temporally





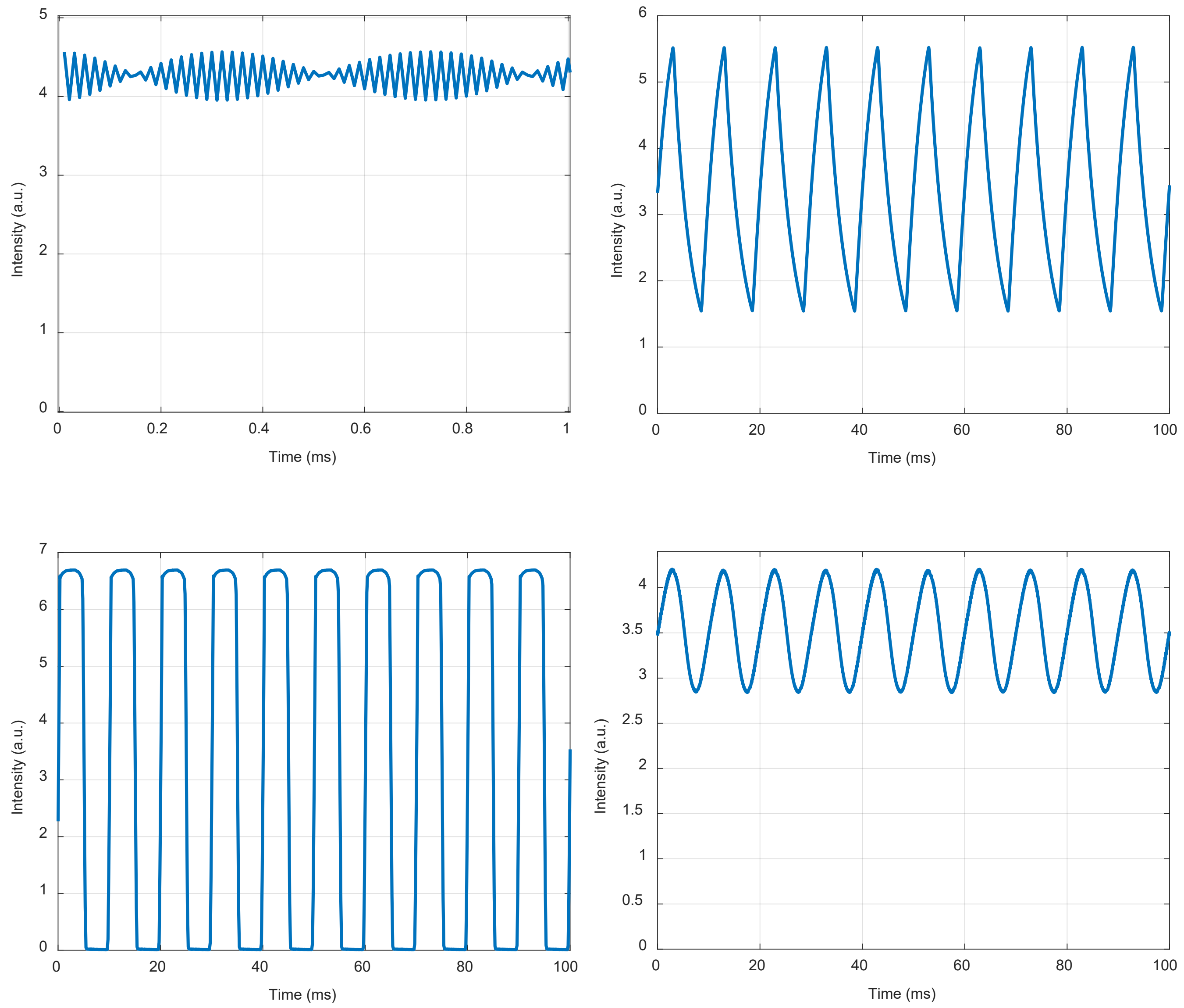
- It's always the driver.
- The LED only mirrors the current from the driver.
- LEDs should have direct current (DC). A **diod** is a rectifier (ensretter).
- TLM shouldn't be a problem.

Temporal Light Modulation (TLM)

Example of a time-modulated light output from LED light bulbs.

Note: It’s never the LED itself causing TLM. It is the DRIVER.

TLM often becomes a problem in various dimming techniques.



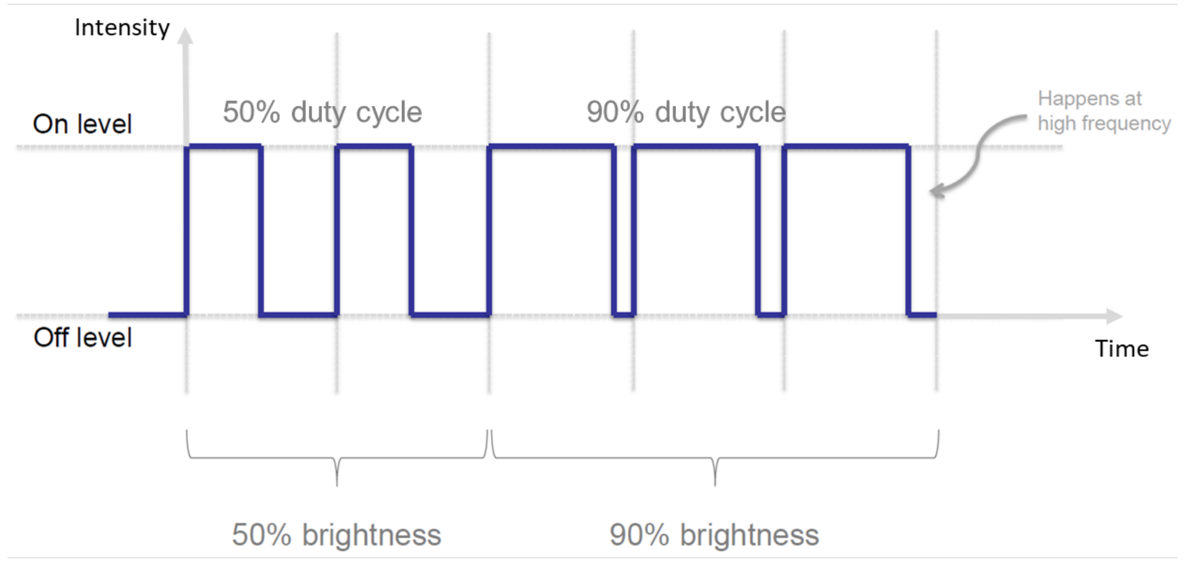
PWM vs. CCR dimming

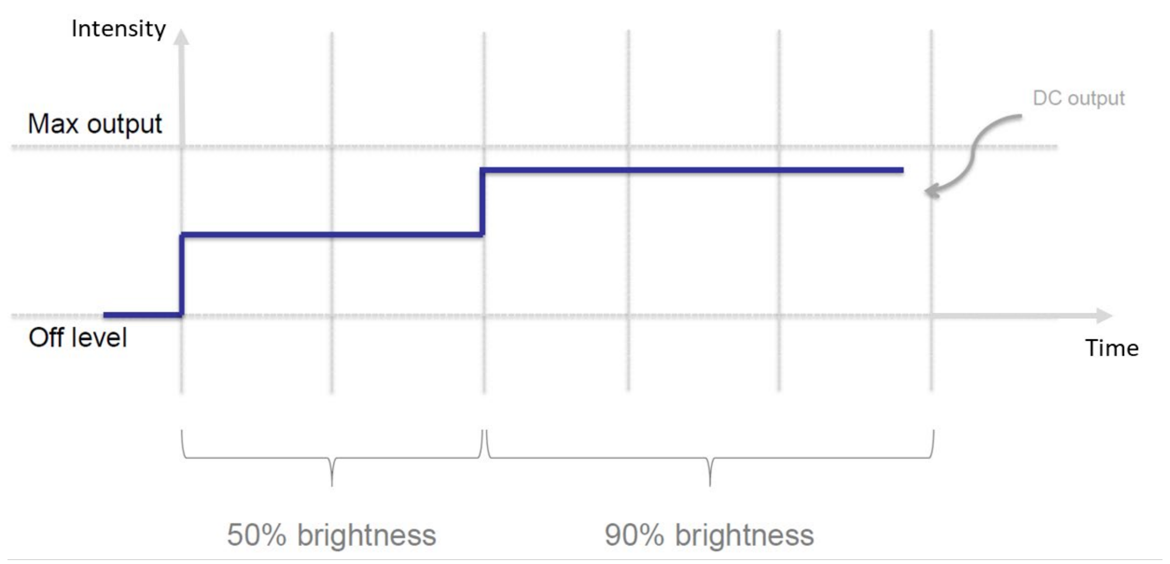
Pulse Width Modulation (PWM) is a dimming technique based on temporal variations. Needs to be at very high frequencies to avoid problems.

- Cheaper components
- Introduce TLM

Constant Current Reduction (CCR) is an alternative dimming technique to PWM. Totally free of temporal modulation, however it might lead to color shift.

- No TLM
- Risk of chromaticity shift





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How to measure TLM

Old ways to assess TLM

- Percent Flicker (note: same as Modulation Depth)
- Flicker Index

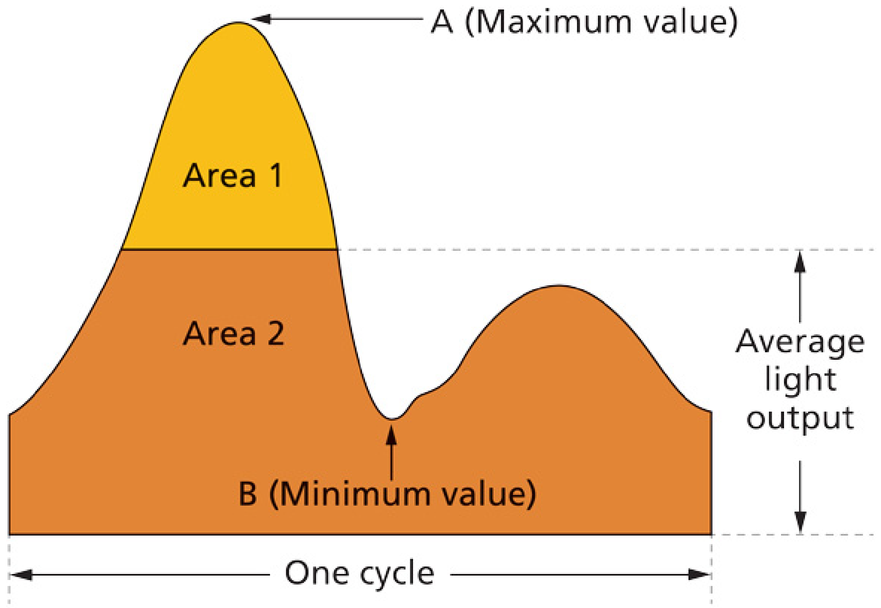
Neither Percent Flicker or Flicker Index take the frequency into account.

Hence, two waveforms can give the same measurement results, but one might cause TLA and one might not (due to difference in frequency).

Other measures are needed.

$$Percent\ Flicker = 100\% \cdot \frac{(A-B)}{(A+B)}$$

$$Flicker\ Index = \frac{Area\ 1}{(Area\ 1 + Area\ 2)}$$



Source: IESNA Lighting Handbook, 10th Edition

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How to measure TLAs

- For **Flicker:**
  Short-term flicker indicator
  Symbol: $\boldsymbol{P_{st}^{LM}}$
  P stands for “Perceptability”
  st stands for “short-term”
  LM stands for “Light Measurement”
  $P_{st}^{LM} = 1$ means 50% chance of observation
- For **Stroboscopic effect:**
  Stroboscopic Visibility Measure (SVM)
  Symbol: $\boldsymbol{M_{vs}}$
  $M_{vs} = 1$ means 50% chance of observation
  Note: The abbreviation SVM is often confused with the symbol M_{vs}
- For **Phantom Array**
  - None existing

No measure addressing subliminal effects. Research needed!

IEC TR 61547-1:2017 Equipment for general lighting purposes - EMC immunity requirements - Part 1: An objecitve light flickermeter and voltage fluctuation immunity test method. (2017).

Sekulovski, D, et al. (2016). *CIE TN 006:2016: Visual Aspects of Time-Modulated Lighting Systems – Definitions and Measurement Models*. http://files.cie.co.at/883_CIE_TN_006-2016.pdf

EU legislation on eco-design

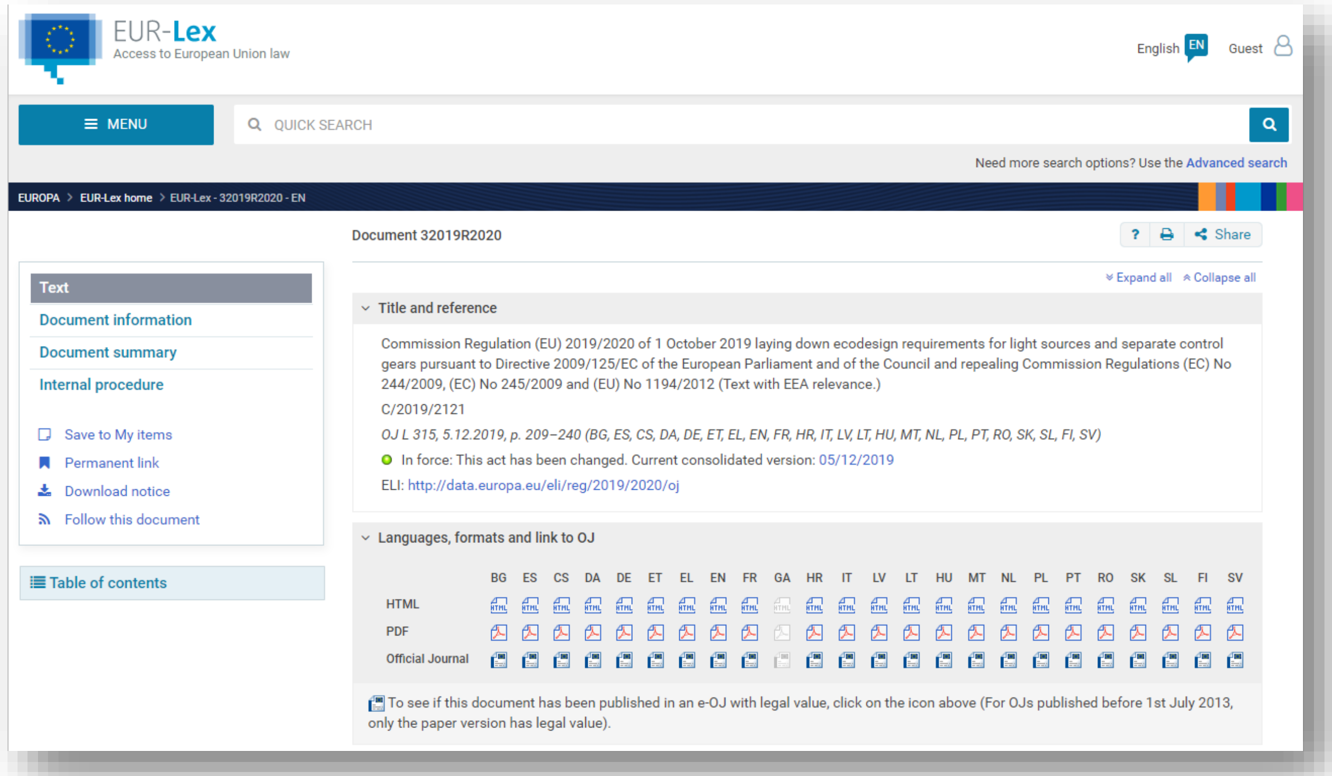
New ecodesign directive contains legislation on levels of flicker and stroboscopic visibility.

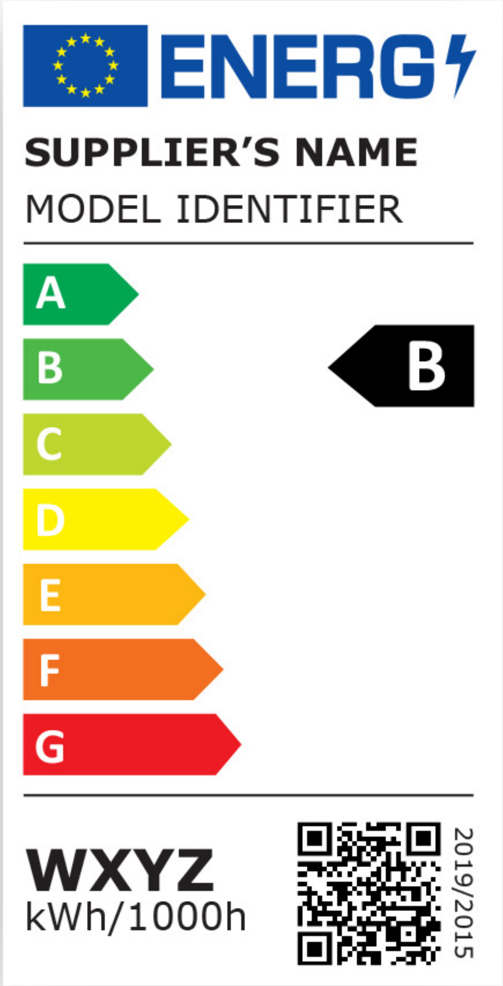
Note: At full load.

TLA	Limit
Flicker	$P_{st}^{LM} \leq 1$
Stroboscopic Visibility	$M_{vs} \leq 0.9$ Expected $M_{vs} \leq 0.4$ from sept 2024

Enter into force September 2021

Expected $M_{VS} \leq 0.4$ in 2024

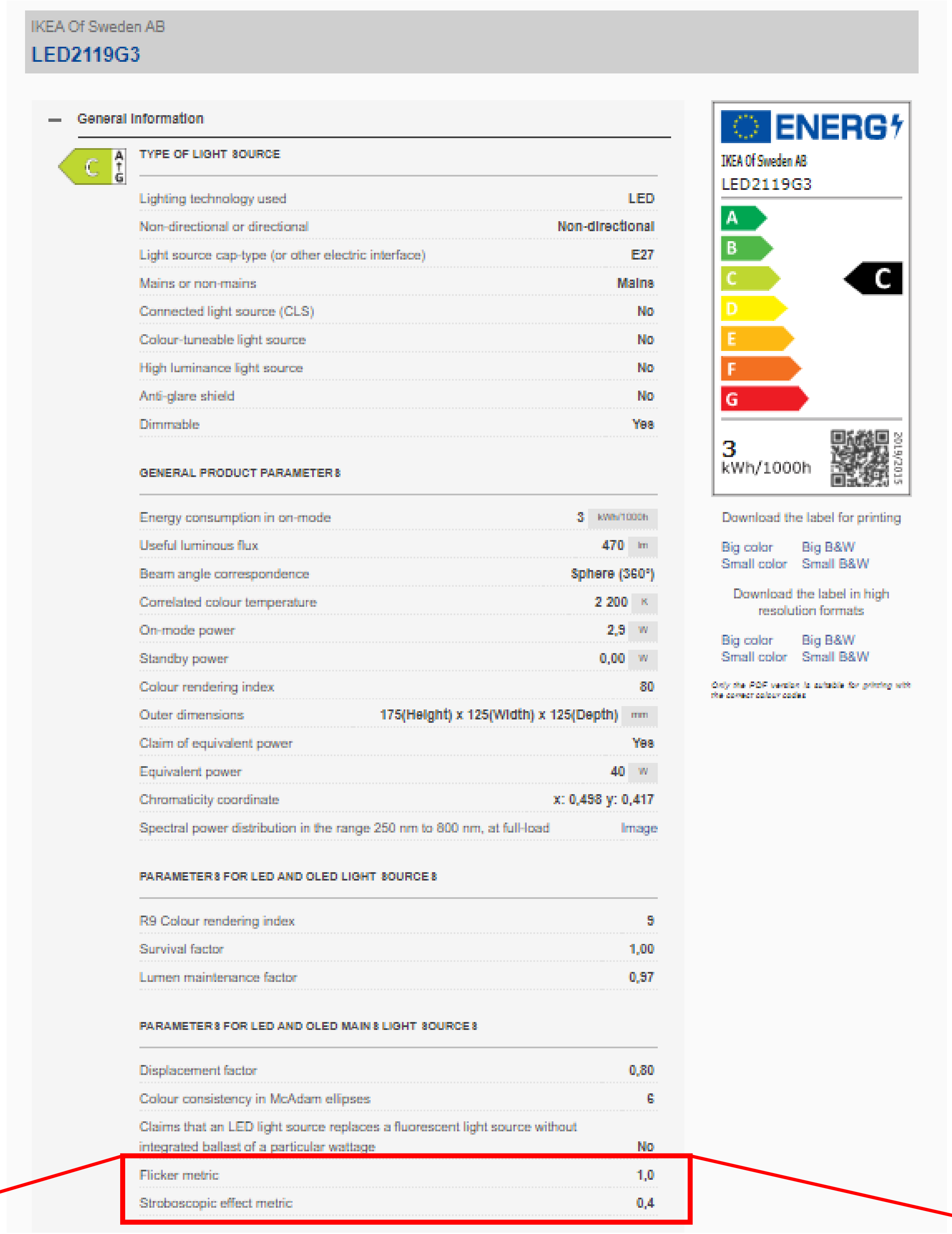




https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2019.315.01.0209.01.ENG&toc=OJ:L:2019:315:TOC
https://ec.europa.eu/energy/en/regulation-laying-down-ecodesign-requirements-1-october-2019

Energy label

- https://eprel.ec.europa.eu/screen/home


IKEA Of Sweden AB

LED2119G3

General information

TYPE OF LIGHT SOURCE

Lighting technology used	LED
Non-directional or directional	Non-directional
Light source cap-type (or other electric interface)	E27
Mains or non-mains	Mains
Connected light source (CLS)	No
Colour-tuneable light source	No
High luminance light source	No
Anti-glare shield	No
Dimmable	Yes

GENERAL PRODUCT PARAMETERS

Energy consumption in on-mode	3	kWh/1000h
Useful luminous flux	470	lm
Beam angle correspondence	Sphere (360°)	
Correlated colour temperature	2 200	K
On-mode power	2,9	W
Standby power	0,00	W
Colour rendering index	80	
Outer dimensions	175(Height) x 125(Width) x 125(Depth)	mm
Claim of equivalent power	Yes	
Equivalent power	40	W
Chromaticity coordinate	x: 0,458 y: 0,417	
Spectral power distribution in the range 250 nm to 800 nm, at full-load	Image	

PARAMETERS FOR LED AND OLED LIGHT SOURCES

R9 Colour rendering index	9
Survival factor	1,00
Lumen maintenance factor	0,97

PARAMETERS FOR LED AND OLED MAINS LIGHT SOURCES

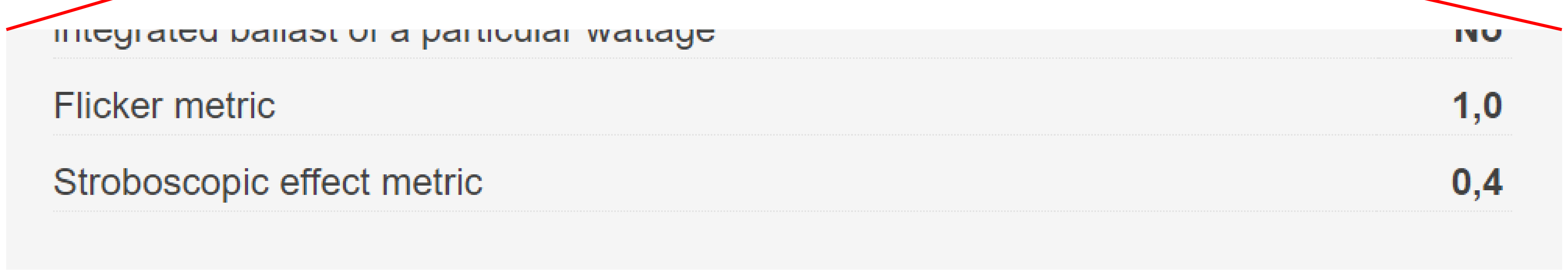
Displacement factor	0,80
Colour consistency in McAdam ellipses	6
Claims that an LED light source replaces a fluorescent light source without integrated ballast of a particular wattage	No
Flicker metric	1,0
Stroboscopic effect metric	0,4

Download the label for printing

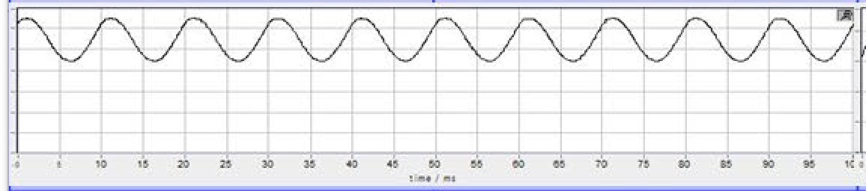
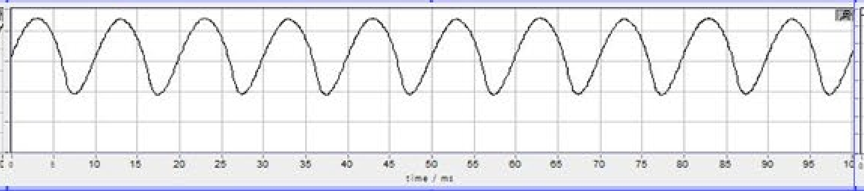
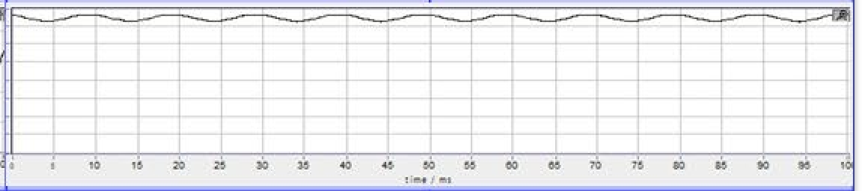
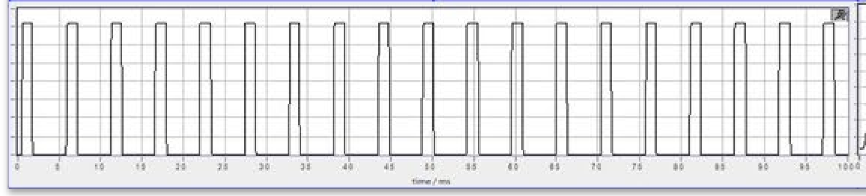
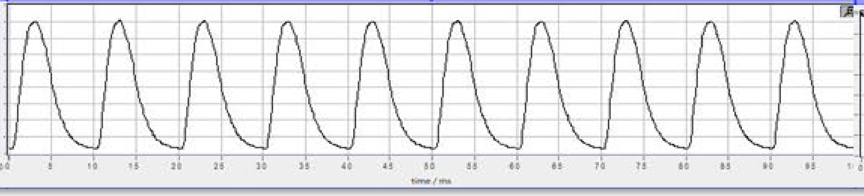
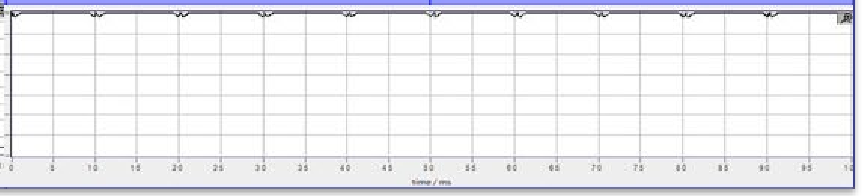
Big color Big B&W
Small color Small B&W

Download the label in high resolution formats

Big color Big B&W
Small color Small B&W

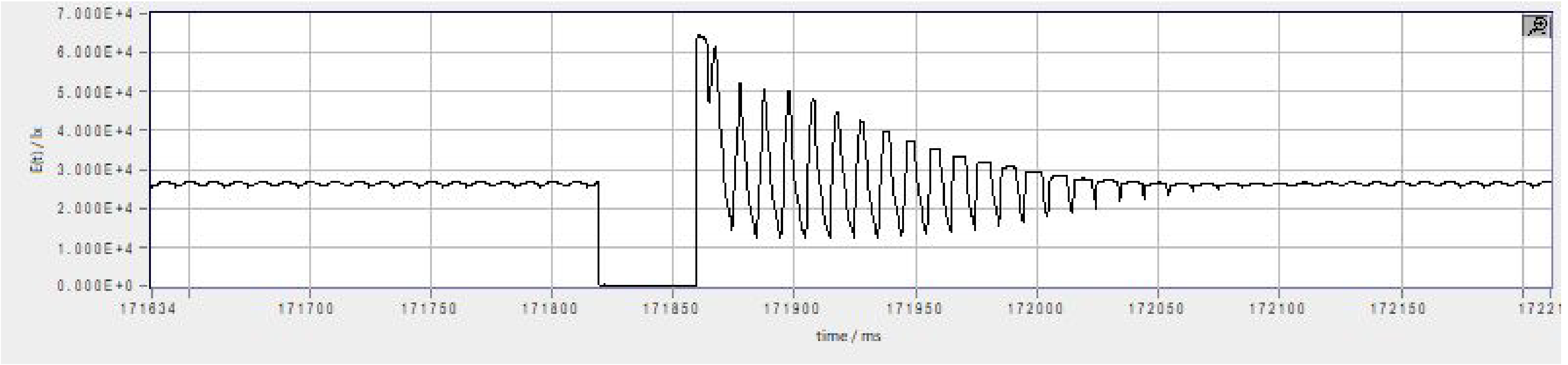


Examples of TLM measurement results

Incandescent 40 W 	Freq: 100 Hz SVM: 0.70 PstLM: 0.13 MD: 19% FI: 0.06	Fluorescent Tube magnetic ballast 	Freq: 100 Hz SVM: 1.32 PstLM: 0.11 MD: 40% FI: 0.12	Fluorescent Tube electronic ballast 	Freq: 100 Hz SVM: 0.09 PstLM: 0.03 MD: 3% FI: 0.01
					
LED PWM 	Freq: 186 Hz SVM: 5.08 PstLM: 7.54 MD: 100% FI: 0.75	LED filament bad 	Freq: 100 Hz SVM: 4.44 PstLM: 0.14 MD: 100% FI: 0.35	LED filament good 	Freq: 100 Hz SVM: 0.02 PstLM: 0.04 MD: 1.6% FI: 0.002
					

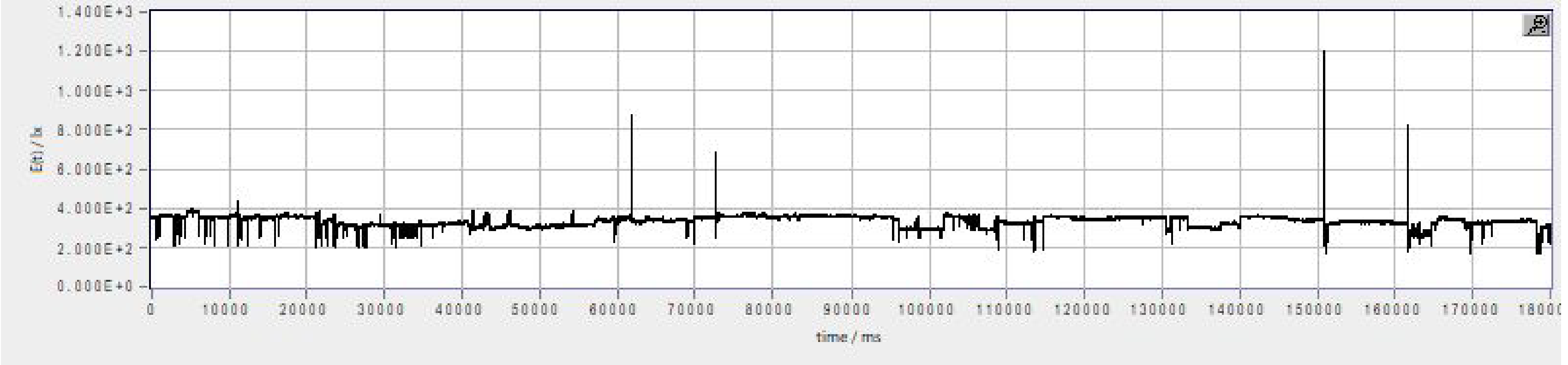
P_{st}^{LM} is a time domain measure

P_{st}^{LM} gives higher readings on **non periodic** changes, such as flashes, outages and transients, compared to periodic behavior.



P_{st}^{LM} = 17
SVM = 0.088

For periodic behavior, SVM is used, as it is a frequency domain measure.



P_{st}^{LM} = 17
SVM = 0.013

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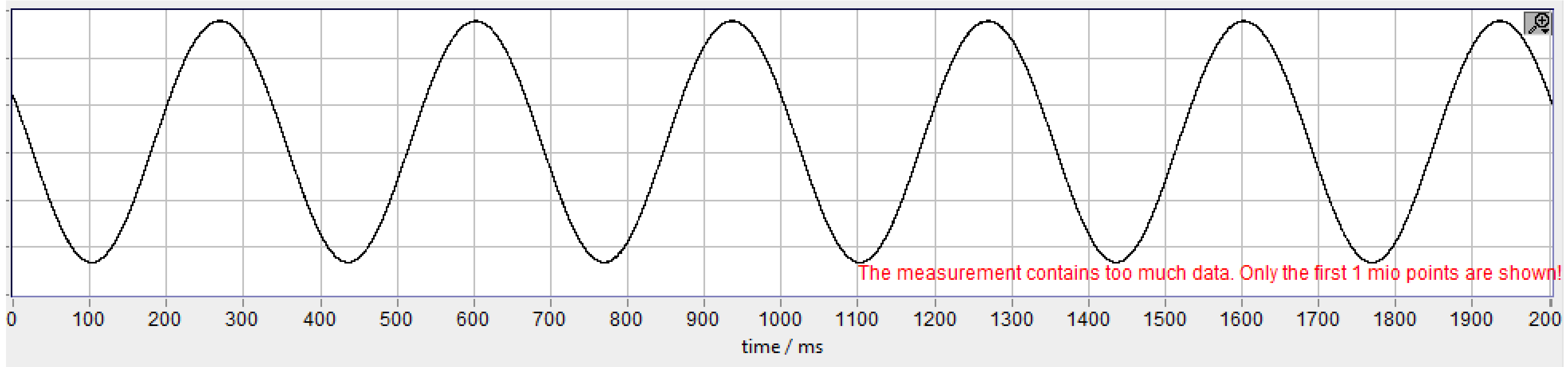
Demonstrations of measurements

Labarazzi

LabFlicker

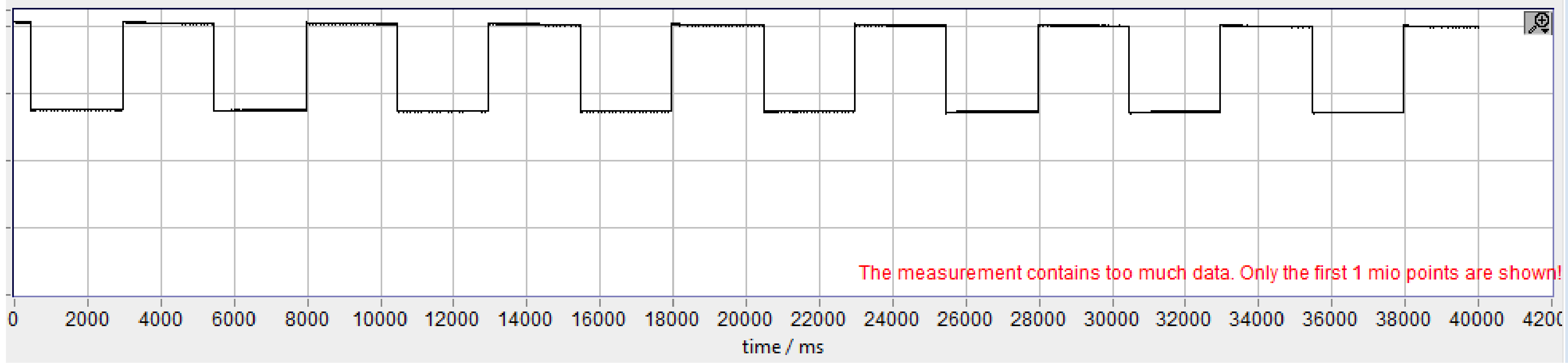
Viso Systems

Exemple of high P_{st}^{LM}



Freq: 3 Hz
SVM: 0.05
PstLM: 49

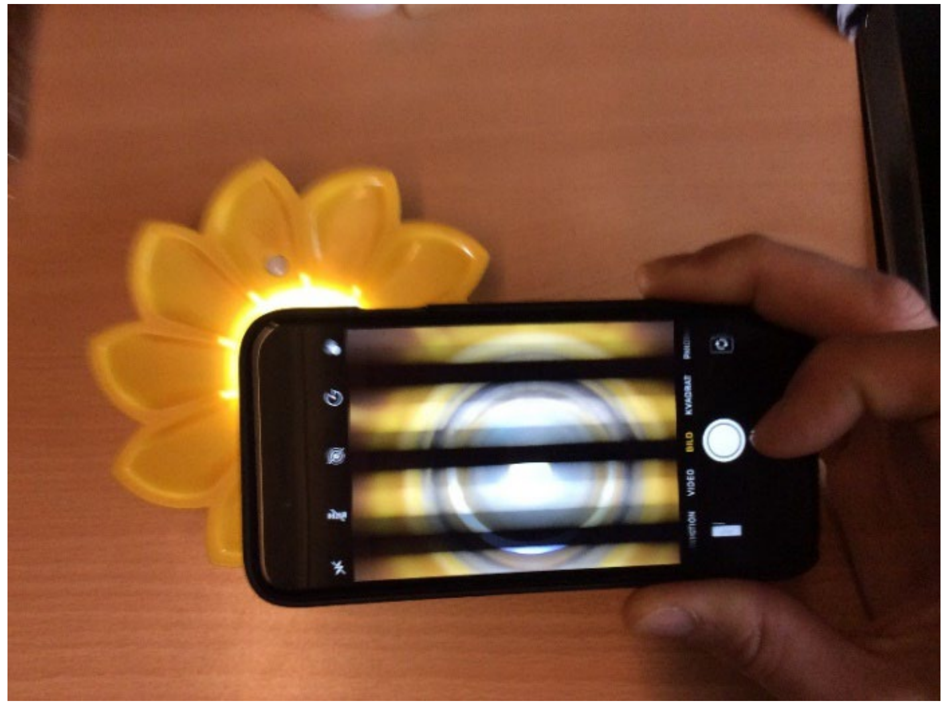
MD: 80%
FI: 0.25



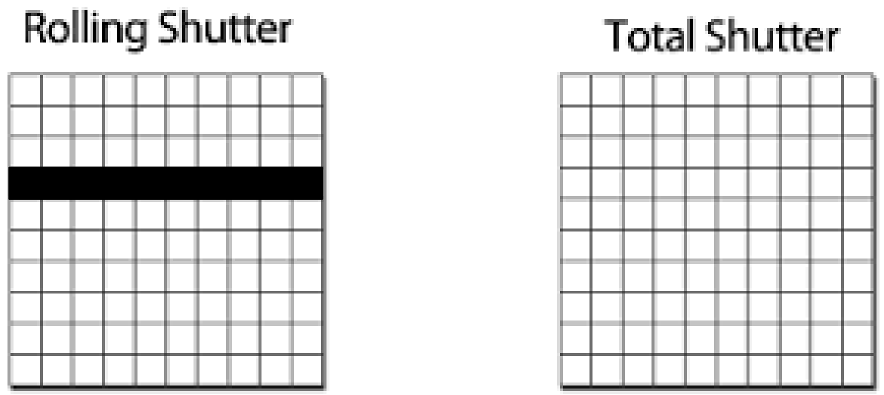
Freq: 0.2 Hz
SVM: 0.01
PstLM: 14

MD: 20%
FI: 0.1

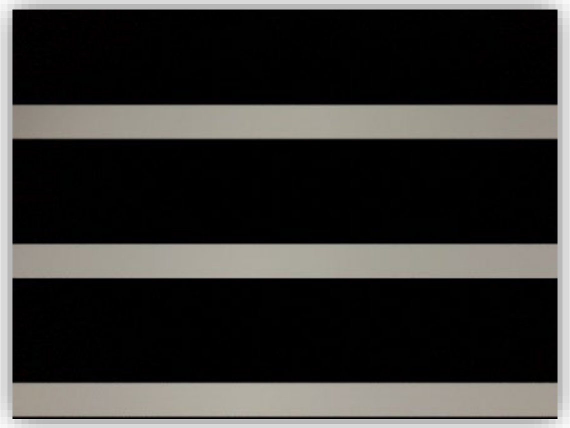
Rolling shutter demo



Mobile cameras use rolling shutter



"Exposure time":



52 µs

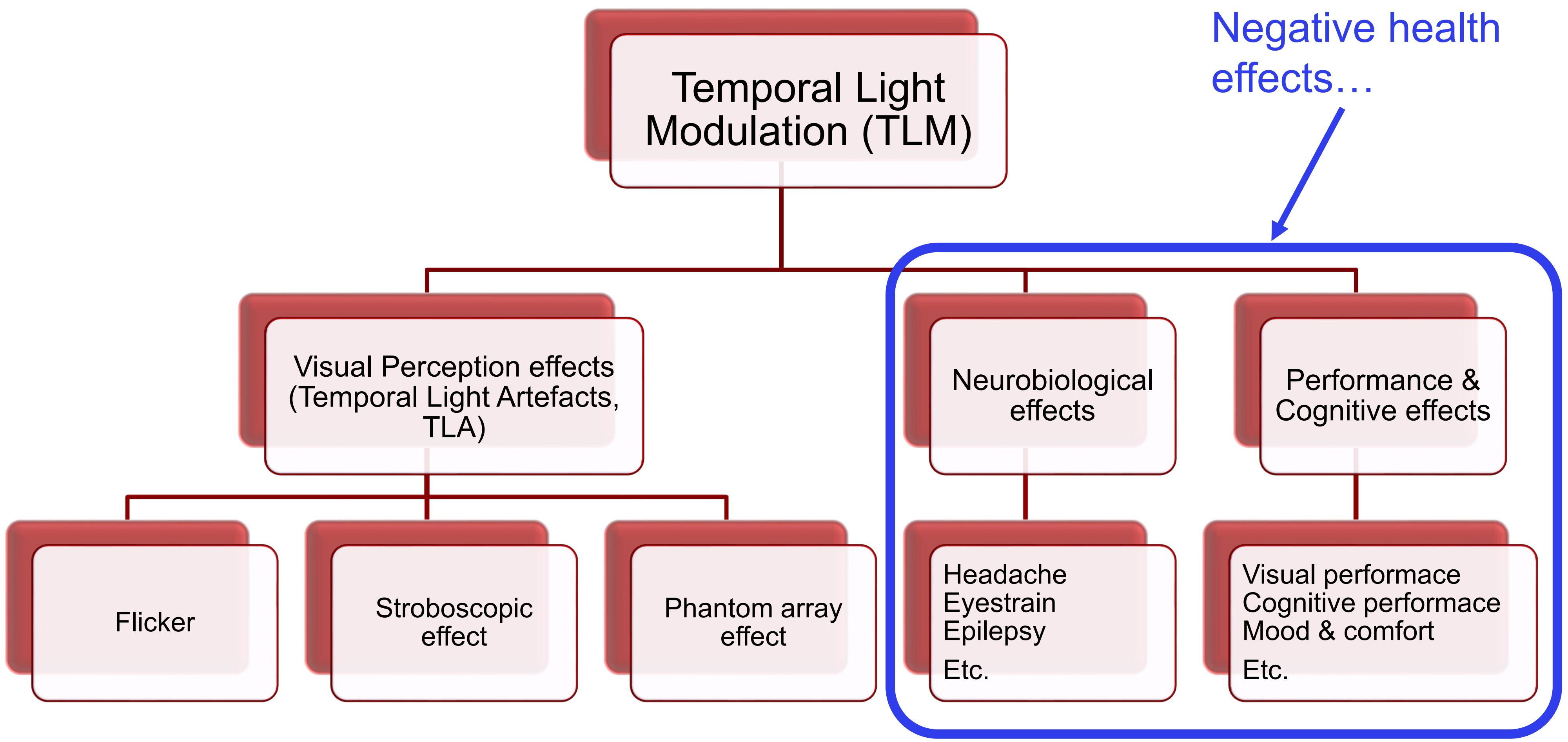
1.5 ms

4 ms

Conclusions:
Mobile phone cameras

- are not good TLM measurement tools
- can serve as a first indicator
- may be able to measure frequency

TLM and health



TLM and humans

- Critical Flicker Frequency (CFF) – The frequency above which flicker is not perceivable. Around 90 Hz. Depends on luminance, periphery/central, size of flickering object, etc.
- Electroretinogram (ERG) measurements have indicated that frequencies up to 200 Hz are still picked up by the human retina even if it's not consciously noticed (might be even higher)[1]
- Psychotropic drugs and alcohol lowers CFF
- Affects reading speed, reading apprehension and visual performance
- Larger eye saccades (fast eye movements) at 100 Hz compared to 20 kHz
- Children are more sensitive compared to adults
- Phantom arrays visible at 11 kHz[2]

1. Berman, S., Greenhouse, D. S., Bailey, I. L., Clear, R. D., & Raasch, T. W. (1991). Human electroretinogram responses to video displays, fluorescent lighting, and other high frequency sources.pdf. Optometry and Vision Science, 68(8), 645–662.
2. Brown, E., Foulsham, T., Lee, C., & Wilkins, A. (2019). Visibility of temporal light artefact from flicker at 11 kHz. Lighting Research & Technology. https://doi.org/10.1177/1477153519852391

Lund University

Respons to TLM

- “Pokemon Incident” of 1997:
  560 epileptical seizures due to 4s of 12.5 Hz blue-red flicker[1]
- Migraine and headaches[2]
- Photophobia[2]
- Hypersensitivity to electricity[3]
- Individuals with autism shows more negative response to TLM
- Stress
- Change in the alpha activity, EEG
- Harder for individuals with dyslexia
- Annoyance

1. Fisher et al., “Photic- and pattern-induced seizures: A review for the Epilepsy Foundation of America working group,” Epilepsia, vol. 46, pp. 1426– 1441, Sep. 2005.
2. Wilkins, A., Veitch, J., & Lehman, B. (2010). LED lighting flicker and potential health concerns: IEEE standard PAR1789 update. In 2010 IEEE Energy Conversion Congress and Exposition, ECCE 2010 - Proceedings. https://doi.org/10.1109/ECCE.2010.5618050
3. Wibom, R. Nyhlén, P. Wennberg, A. (1995). “Flimmer från lysrör. En möjlig bidragande orsak till besvär vid “elöverkänslighet”, Undersökningsrapport 1995:31, Arbetslivsinstitutet, Sverige

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TLM impact on health

- Wilkins found that fluorescent lighting oscillating with a fundamental frequency component of 100 Hz and with a modulation depth of 45% induced headaches in office workers. Headaches and eyestrain were reduced by a factor of two or more when the controlling circuitry was changed to high-frequency ballasts (32 kHz).

  Wilkins, A. J., Nimmo-Smith, I., Slater, A. I., & Bedocs, L. (1989). Fluorescent lighting, headaches and eyestrain. *Lighting Research & Technology*, *21*(1), 11–18. https://doi.org/10.1177/096032718902100102

- Visual performance scores were found to be significantly higher in a high-frequency fluorescent illumination (between 20 and 60 kHz) compared to lower frequency illumination (120 Hz).

  McColl, S. L., & Veitch, J. A. (2001). Full-spectrum fluorescent lighting: a review of its effects on physiology and health. *Psychological Medicine*, *31*(6), 949–964. https://doi.org/10.1017/S0033291701004251

- Visual performance (using discrimination and simple search tasks) under lighting with low (3%) and high (32%) temporal modulation was reduced as temporal modulation increased, even though the two conditions were not perceptually different from each other.

  Jaén, E. M., Colombo, E. M., & Kirschbaum, C. F. (2011). A simple visual task to assess flicker effects on visual performance. *Lighting Research and Technology*, *43*(4), 457–471. https://doi.org/10.1177/1477153511405409

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Pre-tests

2021 Christmas calendar episode of LTH
5 min youtube clip (in Swedish)

https://youtu.be/zkY5FW00GPY

Or search ”LTH julkalender flimmer”

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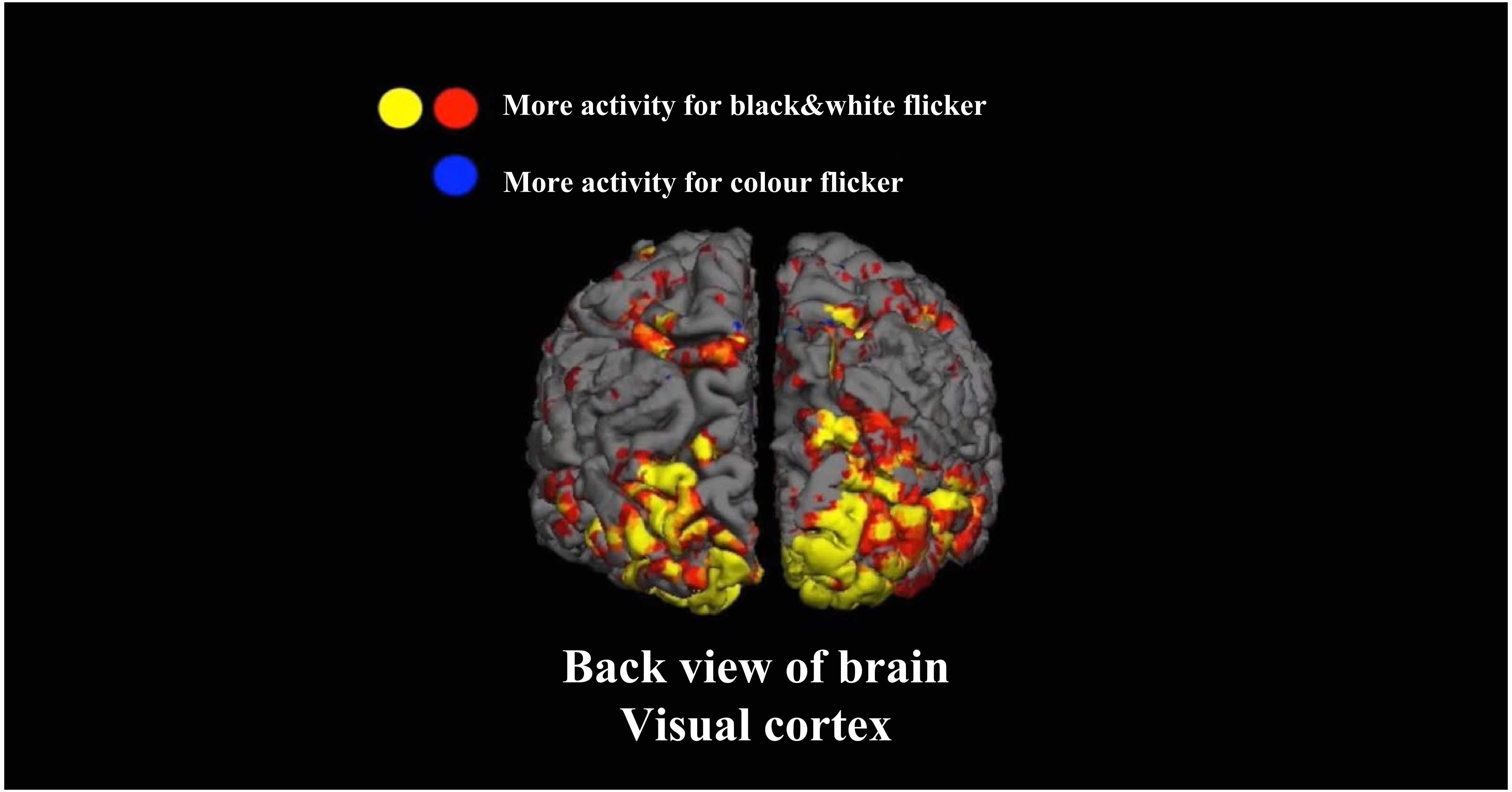
Pre-tests



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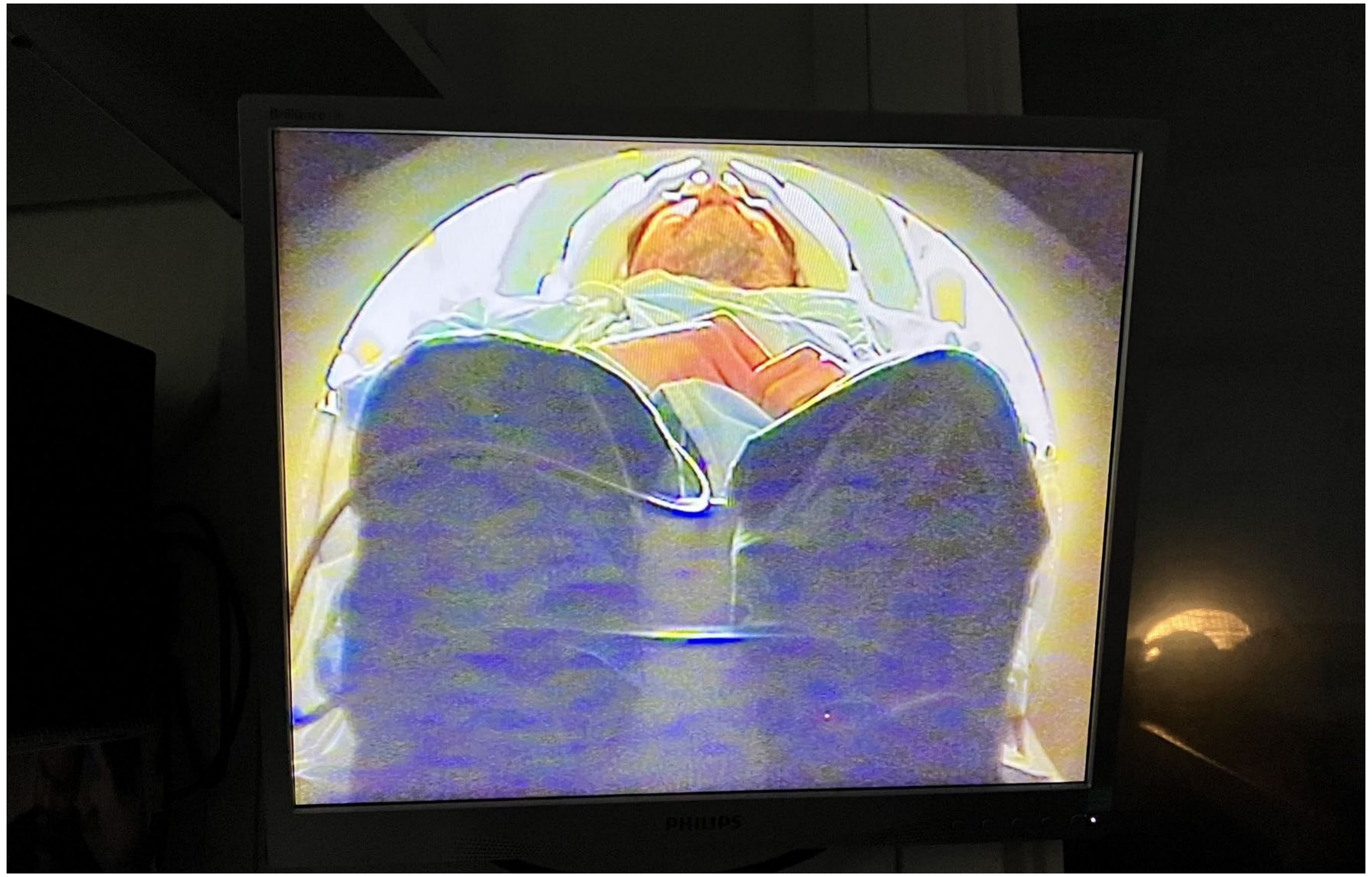
LTH
LUNDS TEKNISKA HÖGSKOLA

fMRI-fLICKER – How flicker effects the brain

- Project period: 2022 sept. – 2024 aug.
- Funded by Swedish Energy Agency
- Budget: 3 MSEK
- Multidisciplinary
  - Visual ergonomics at Design Sciences at Lund University
  - Department of Medical Imaging and Physiology (BoF) at Skåne University Hospital
  - Department of Clinical Sciences, Lund University
  - Department of Psycholoy, Lund University
- Objective:
  To investigate how light flicker of different types give rise to brain activation. The overall aim is to obtain scientific basis for formulating a measure and limit values for neurological impact on the brain, caused by light flicker.

Energimyndigheten

fMRI-fLICKER – how flicker effects the brain



Project status

- 23 healthy subjects scanned during spring 2023
- Plan to scan ca. 35 subjects with mild migraine during autumn 2023
- Data analysis during spring 2024
- Submission of publication before summer 2024

Questions?

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Contact: johannes.linden@design.lth.se

Welcome to join our network,
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