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LUMEN or CANDELA as SI *base* unit -

Summary of CIE D2 discussions on this proposal for end-user

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THE COMMISSION

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- 1400 Experts (Scientists, Standardization Officers, Lighting Designers,…)
- NMIs, Measurement Labs, Universities, Companies,…
- 41 National Committees in all Continents
- 7 Divisions
- 120 Scientific Project Groups (Technical Committees)
- Founded 1913

Importance of Light

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- 50 billion EUR business for products
-19% electrical energy spent for lighting
-230 billion EUR costs for electricity
- >80% perception of outside world through vision

Historical change:

LED penetration in the market
– EU: 2009: 1,7 %, 2010: 6,2%, 2011: 12,8%
– McKinsey: 2016: 45%, 2020: 70% (general lighting)

Luminous efficacy:
incandescence: 10 to 15 lm/W
CFLs: 50 to 80 lm/W
LED: 120 lm/W (today) to 200 lm/W (2015)

Importance of Photometry

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regulations on energy efficiency

performance requirements

SSL products

Emerging technology

New devices, new properties
New players on the market

globalization of the market

Compatibility, competition

- > Need for trustful measurement results

The SI is the backbone of the system

SI base units

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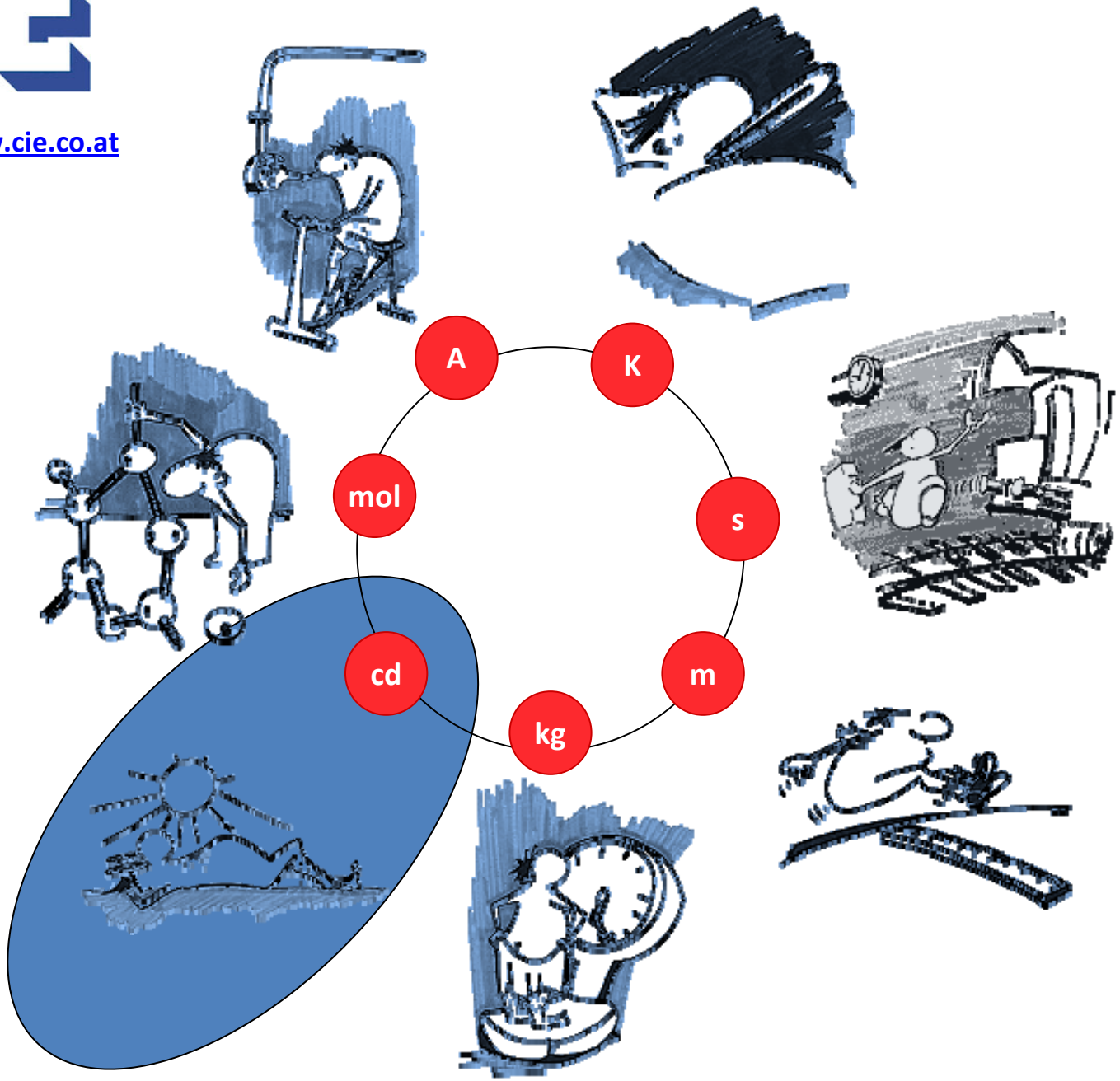

Reformulation of the Candela Definition

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The candela, unit of luminous intensity in a given direction, is such that the luminous efficacy of monochromatic radiation of frequency 540 x 10^{12} hertz is equal to exactly 683 candela steradian per watt.

Thus we have the exact relation K_{cd} = 683 lm/W. The effect of this definition is that the candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 ×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.

Principle Governing Photometry

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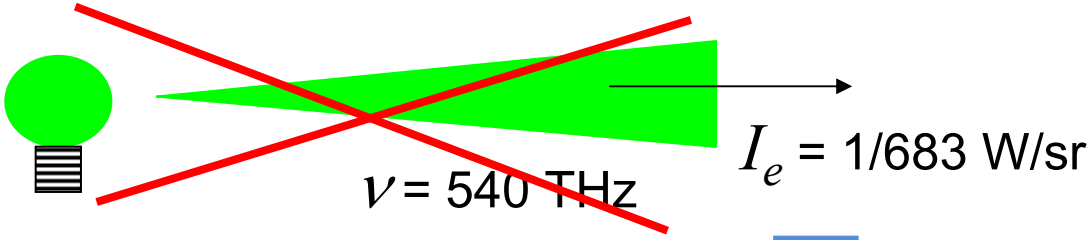
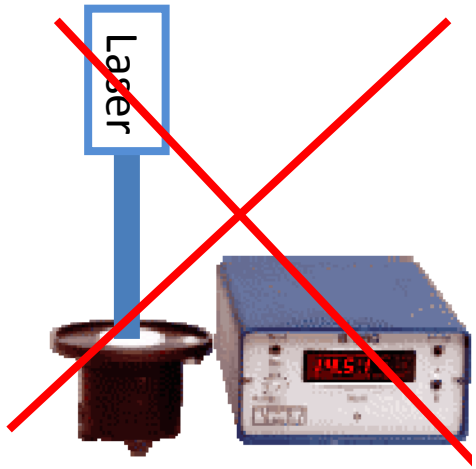
Spectral distribution: broadband

"Single wavelength radiation is useless photometry"



Angular/spatial distribution: broad

"In photometry a detector is never under-filled"



An observer has to be defined

Photopic – Scotopic – Mesopic – 10°,…

From Radiometry to Photometry detector based

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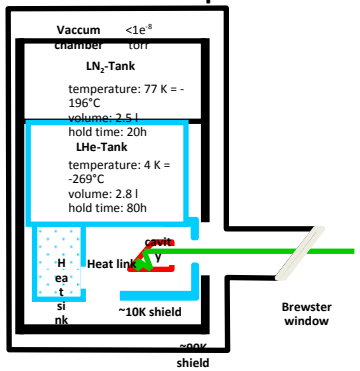
Electrical quantities

Radiometric quantities



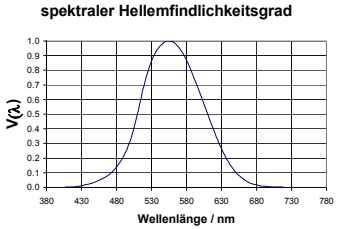
Cryogenic radiometer

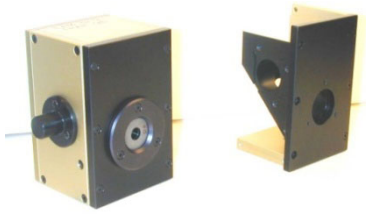
Power

P_{el} - > P_{opt}

W

Photometric quantities: photometer





-spectral broadband
-overfilled

Illuminance responsivity

A /lx, V/lx

BTW: Lowering the uncertainty of the electrical or radiometrical realizations has little influence on the photometric scale (i.e. a calibrated Si-Trap is sufficient)

From Radiometry to Photometry source based

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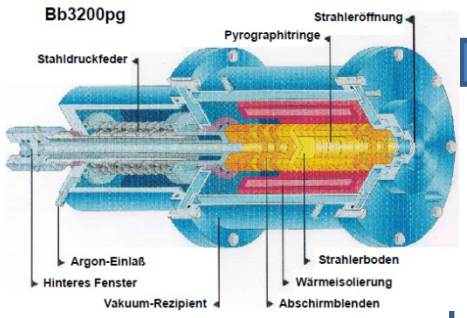
Radiometric quantities

Black body radiator



Spectral radiance W/nm/sr/m2

Luminance cd/m^2

Photometric quantities: Set of standard lamps

Luminous intensity cd

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Photometric «base» quantity?

- luminous flux (lm)?
- Illuminance (lx)?
- Luminous intensity (cd)?
- Luminance (cd/m^2)?

It dependes…

Metrology (detector based): illuminance
Metrology (source based): luminance, luminous intensity
Vision : ?

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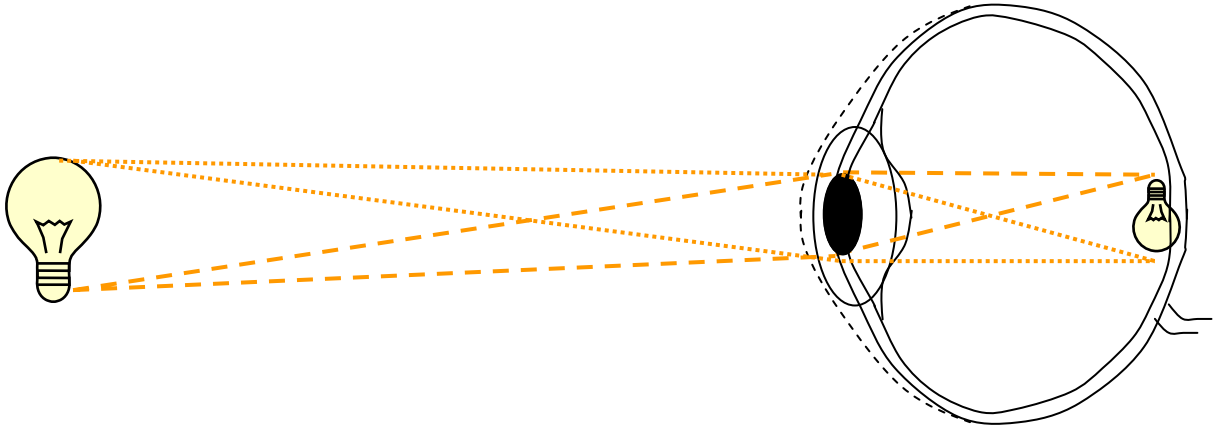
Vision, perception

Luminance is the most fundamental quantity

$$L = \frac{\mathrm{d}^2 \Phi_\mathrm{v}}{\mathrm{d}\Omega \cdot \mathrm{d}A \cos\theta}$$



-> In an ideal optical imaging system the luminance/radiance is maintained!

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Blevin/Quinn arguments for Lumen

1. In radiometry the quantity flux and its unit the watt are universally regarded as
   more fundamental than the quantity radiant intensity and its unit the watt per steradian….The derived quantities have to be given in the opposite and less logical order of the precedence.

   Reply: Realising the unit requires a defined geometry, and luminous intensity is the simplest of these.

Blevin/Quinn arguments for Lumen

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2. the term «intensity» is probably the most overworked and ambigous term in optics. Most physicists without a photometric backround use it in ways that conflict with photometric use (i.e. «square of the wave amplitude», «radiance» in radiative transfer theory)… It is «unfortunate» that the quantity whose name has such a diverse use should have its units chosen as a basic unit.

Reply: It is not really the problem of unit but of the quantity. There are many other cases where quantities have different meanings (weight versus mass)

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Blevin/Quinn arguments for Lumen

3. Yet another reason for preferring the lumen as the basic unit is the restriction of the concept of luminous intensity to sources as discussed in Section 2. The quantity luminous flux is applicable wherever there is visible radiation, and Reference to the total luminous flux emitted by a source is only an example of one particular use of this quantity.

Reply: Lumen in a beam is useless for practical photometry. The lumen (as used in photometry) is not realizable by itself—it requires a geometry, which leads to the other photometric quantities.

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Blevin/Quinn arguments for Lumen

4. Problems arise with the practical realisation of the luminous intensity of the light source: it has to be a point source (hypothetical case), and it is not measureable directly but through the illuminance at a give distance.

Reply: Many quantities of base units are realized indirectly (i.e. Meter), Choosing the distance correctly even the larges source can be considered as point source. Residual errors can be corrected mathematically.
The measurement of the total luminous flux of a lamp is not simple either.

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Bleving/Quinn arguments for Lumen

5. I remark that the names of the other base units of the SI are very familiar not only to the scientific world but also to the public in general, particularly children and students, simply because they are mostly in everyday use. Who has not used the names second, metre, kilogram, ampere, kelvin (perhaps a bit less) and mole or seen them on meters or packages or clocks? But few have ever seen or used the name candela in everyday life, yet ones buys lamps these days with lumen written on them.

Reply: This is true in other fields also: in electricity the units Watt and Volt are much more used in general public than Ampere.

The name 'candela' is a very descriptive name, one which the general public can easily appreciate as being related to vision. This means that although the definition may sound 'complicated', people instinctively have a feel for what it conveys.

Conclusions of CIE D2

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The change of the definition of the Candela in 1979 was very fundamental.
A change from Candela to Lumen has no real practical benefit, in contrary, the geometrical aspects of photometry becomes hidden.

In the absence of compelling reasons to change from the candela to the lumen as the base SI unit, it is highly recommended to maintain the status quo.

9th edition SI Brochure, draft 090823, chapter 2.1:
The choice of which units to take as base units is to some extent arbitrary. This choice has been governed by history and tradition in the development of the SI over the last 120 years.

Feedback from the user community: There are many more important aspects in modern photometry than the choice of its base unity…