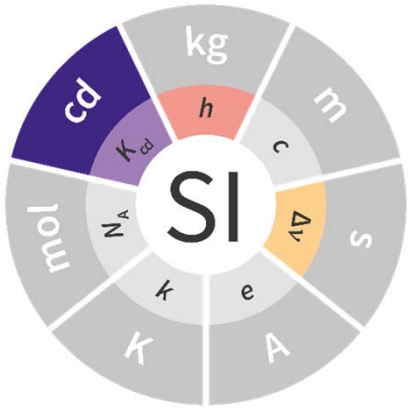
CCPR Report to the CCU

24th Meeting of the CCU

Bureau International des Poids et Mesures

What is new - cd

- Introduction of **defining constant** for photometry, K_{cd} ***luminous* efficacy** of monochromatic radiation of frequency 540×10^{12} Hz
- **Reformulation** of definition of the candela
  - (not a redefinition), to bring it in **explicit constant** form:



THE CANDELA

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 540×10^{12} Hz, K_{cd}, to be 683 when expressed in the unit lm W^{-1}, which is equal to cd sr W^{-1}, or cd sr $kg^{-1} m^{-2} s^3$, where the kilogram, metre and second are defined in terms of h, c and $\Delta\nu_{Cs}$.

Bureau International des Poids et Mesures

What is new - cd

- K_{cd} makes a direct link between photometric and radiometric quantities for monochromatic radiation of frequency 540 THz

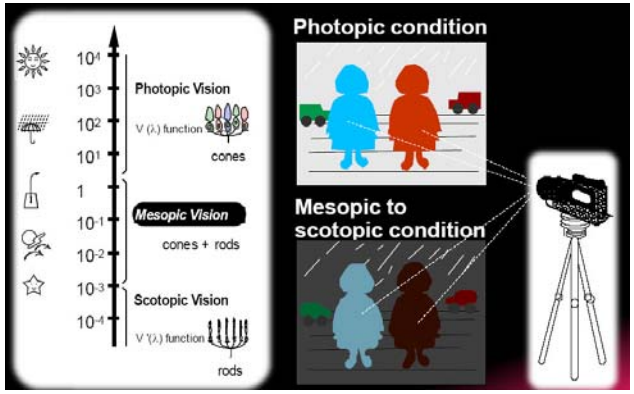
flux	illuminance	intensity	luminance
lm $\leftrightarrow$ W	lx $\leftrightarrow$ W·m^{-2}	cd $\leftrightarrow$ W·sr^{-1}	cd·m^{-2} $\leftrightarrow$ W·sr^{-1}·m^{-2}
K_{cd}	K_{cd}	K_{cd}	K_{cd}

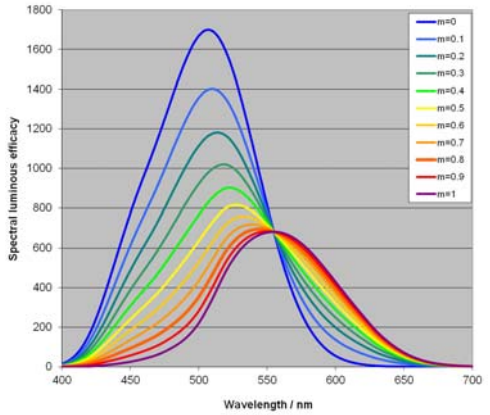
- *Mise en pratique* for the definition of the candela in the SI (20 May 2019)
- BIPM report 05/2019: Principles governing photometry (20 May 2019)
- Appendix 3 Units for photochemical and photobiological quantities (20 May 2019)

Bureau International des Poids et Mesures

What is new

- New agreed **human visual response function** (**mesopic and 10°**)

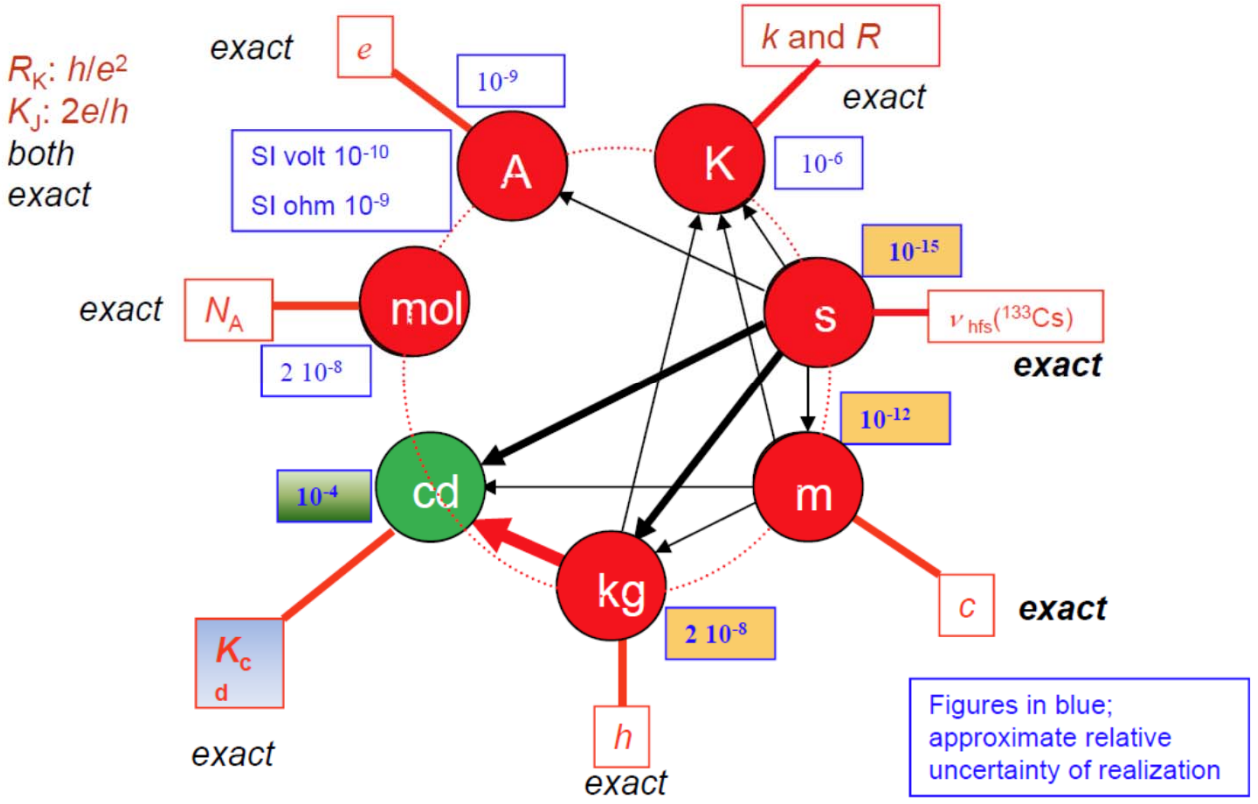




- Radiometric (W) and photon flux based system (s^{-1})

Bureau International des Poids et Mesures

revised SI: Impact on cd (and lm and lx)



Bureau International des Poids et Mesures

Impact of 4 redefinitions on the candela (1)

cd is linked to kg

What one would expect:

$$\left|\frac{\mathrm{kg}_h - \mathrm{kg}_{\mathrm{IPK}}}{\mathrm{kg}_{\mathrm{IPK}}}\right| \leq 2\times10^{-8}$$

$$\left|\frac{\mathrm{cd}_{\mathrm{new}} - \mathrm{cd}_{\mathrm{old}}}{\mathrm{cd}_{\mathrm{old}}}\right| \leq 2\times10^{-8}$$

c.f. 10^{-4} uncertainty in realization of candela:

Redefinitions: **No significant impact on the candela**

But this is not the whole story...

Bureau International d Poids et Mesures

Impact of 4 redefinitions on the candela (2)

Today, many NMIs realize the candela by radiometric methods

- **The primary realization of radiometric quantities (i.e. kryogenic radiometer)** is based on a electrical substitution method. The revised SI has changed the practical realization of the electrical power (W) by $2 \cdot 10^{-7}$, and the electrical current by $9 \cdot 10^{-8}$.
- Best uncertainties in radiometric measurements: 10^{-5}
- Conclusion: **No detectable effect** on radiometric measurements

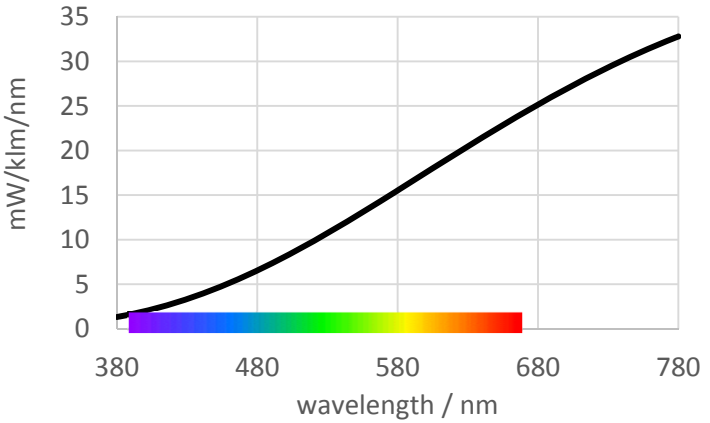
Bureau International des Poids et Mesures

But this is not all…

Impact on CIE standard Illuminant A

- All photometric devices are calibrated referring to CIE standard illuminant A, realized by designed incandescent lamps.
- CIE standard illuminant A is defined in 1924 through an ideal blackbody radiator with a distribution temperature of T_A = 2848 K
- The relative spectral distribution $S(\lambda)$ of a blackbody radiator, given by Planck's law, includes *h*, *c*, and *k*

$$S(\lambda) \propto \frac{1}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k T_A}} - 1}$$



Bureau International des Poids et Mesures

Impact on CIE standard Illuminant A (2)

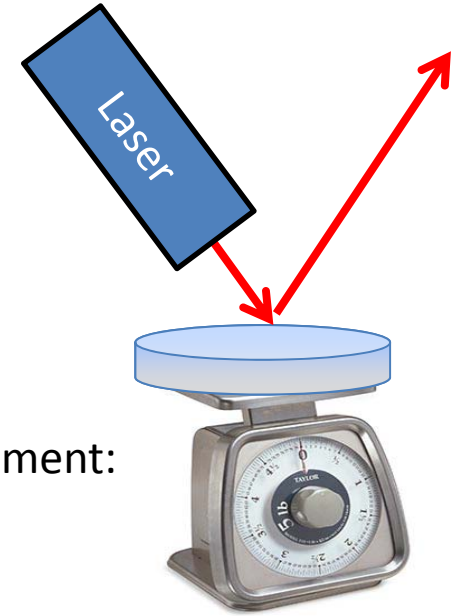
- to keep the spectral distribution unchanged the distribution temperature has to be changed each time the values of *h*, *c*, and *k* change
- last value based on ITS-90: T_A = 2855.542 K that was typically rounded to 2856 K
- Revised SI changed the value by -46 mK: T_A = 2855.496 K which should be rounded to 2855 K
- Uncertainty of distribution temperature measurements is about 5 K to 10 K
- CIE recommends now the "definitive" value of 2855.5 K for the practical realization of standard illuminant A

Revised SI: potentially new routes of traceability

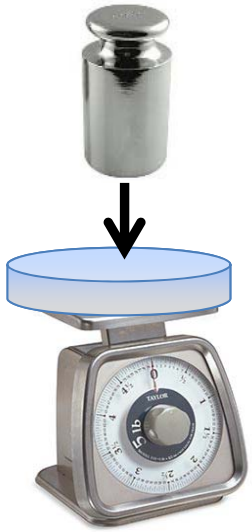
- Link optical power directly to kilogram (photon momentum: $p = h / \lambda$)

1 W ≈ 1 µg

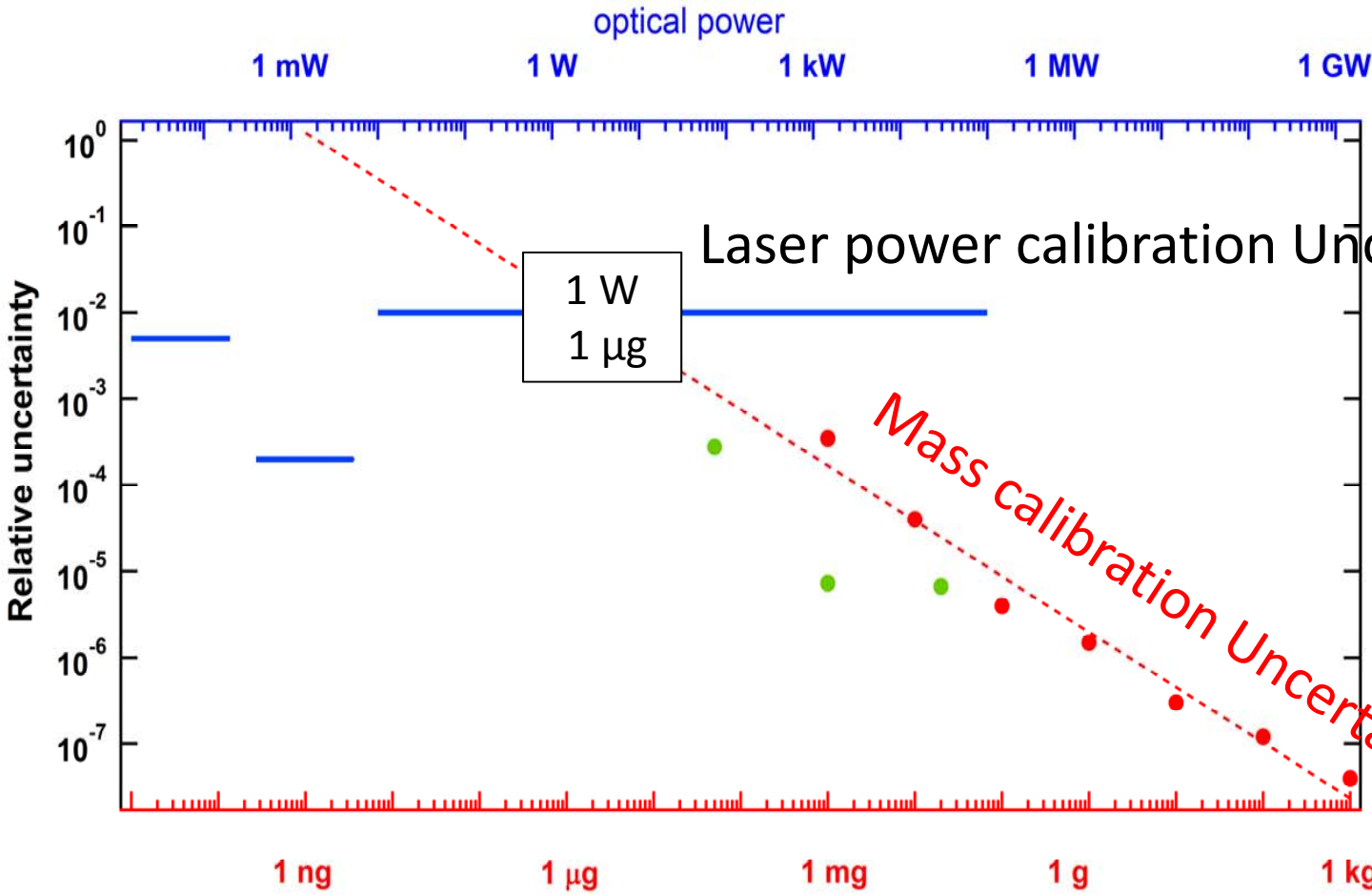
Measurement:



Calibration:

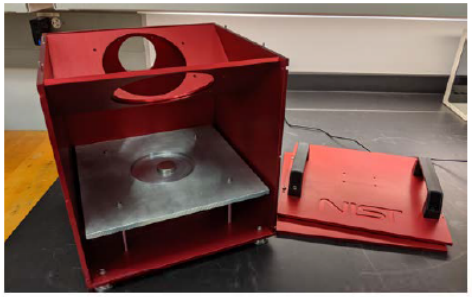


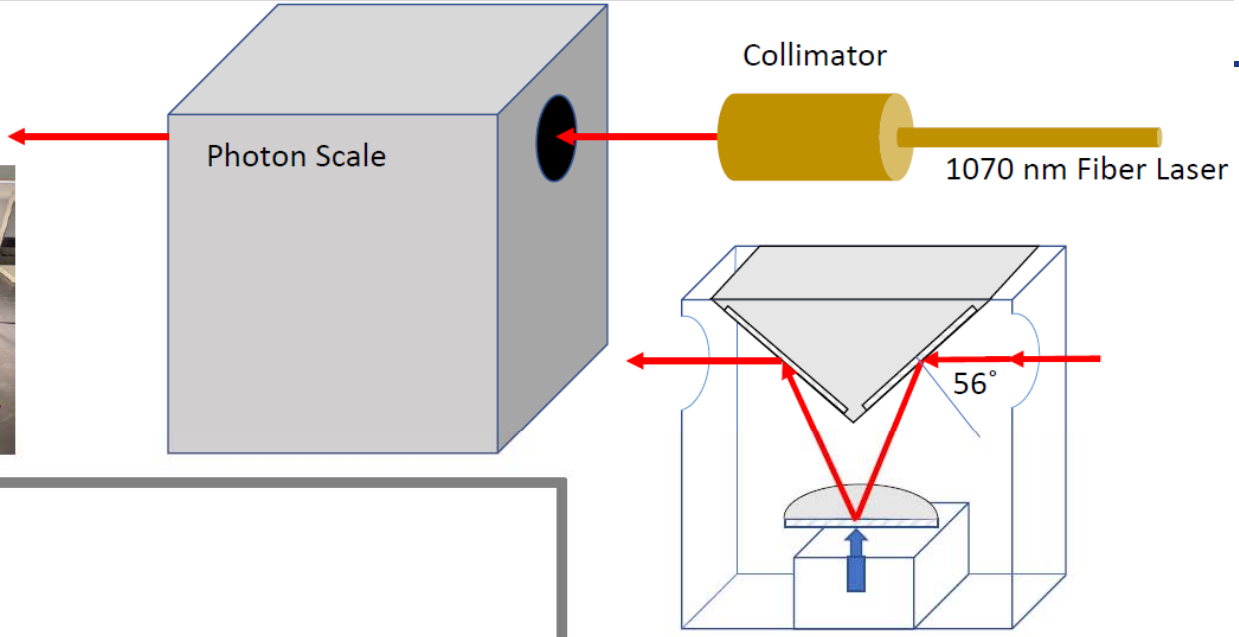
Bureau International des Poids et Mesures



With Gordon Shaw, David Newell, Stefan Schlamminger, NIST

BeamBox (next generation of RPPM) “calibrated source”





Specifications

Dimensions:

30x30x30 cm^3

Power:

Minimum detectable

2 W

Noise-equivalent power non-laboratory 10 W/√Hz

Response time:

Settling time

< 1 sec

Thank you

Bureau International des Poids et Mesures

www.bipm.org