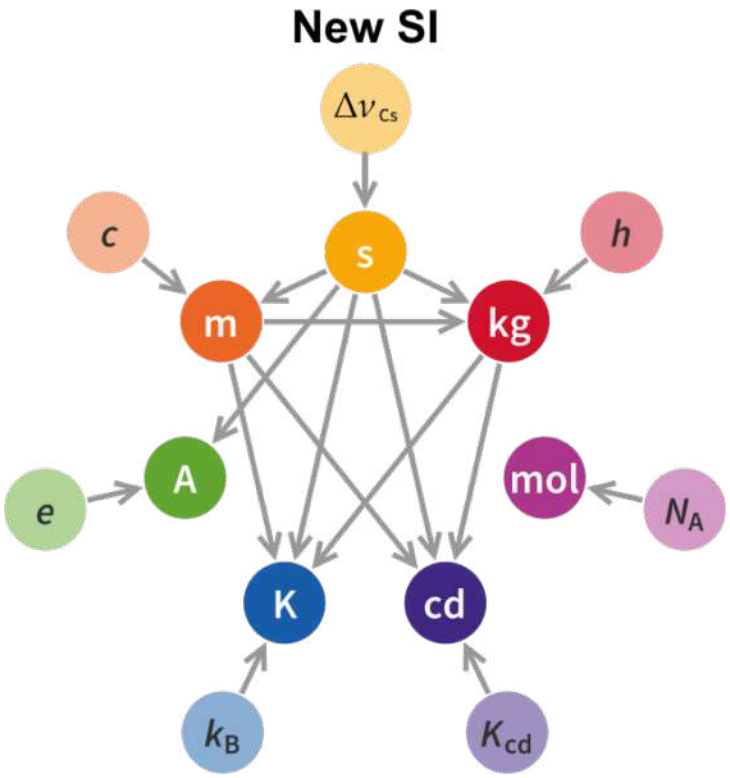
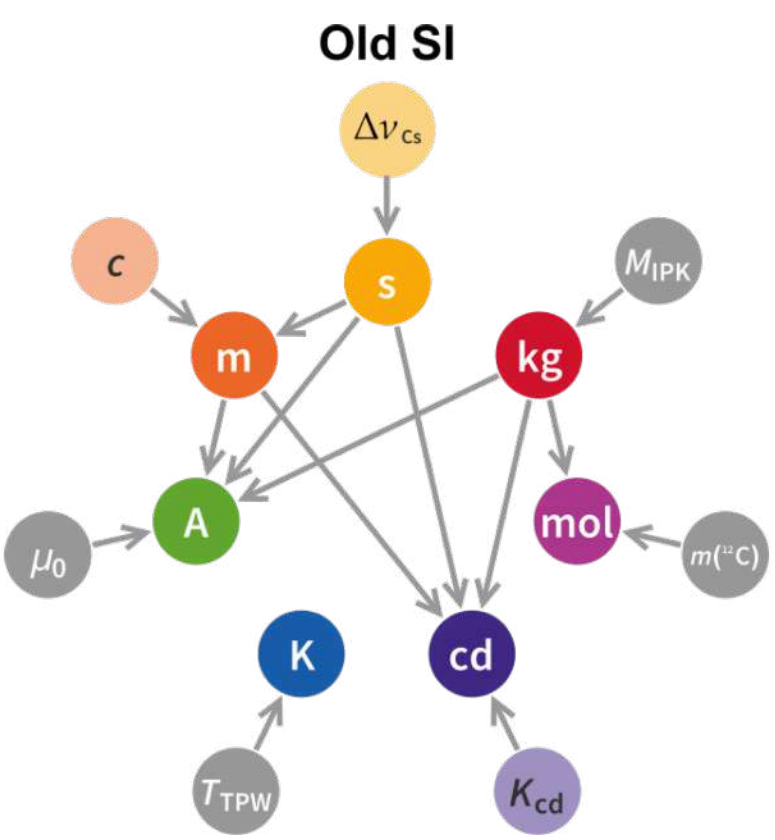
Het nieuwe SI:
le Système International nouveau est arrivé



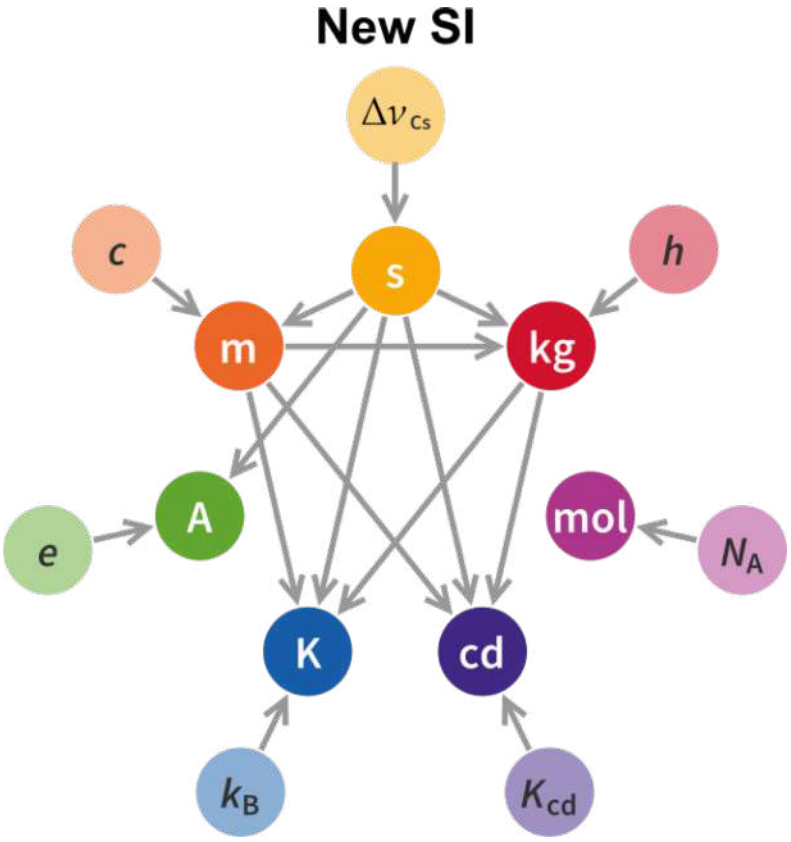
SI: Système International (d'unités)
International System of Units
Internationale Stelsel van Eenheden

Klaasjan van Druten, Viva Fysica, 24 januari 2020

May 20, 2019: the new SI



1983-2019

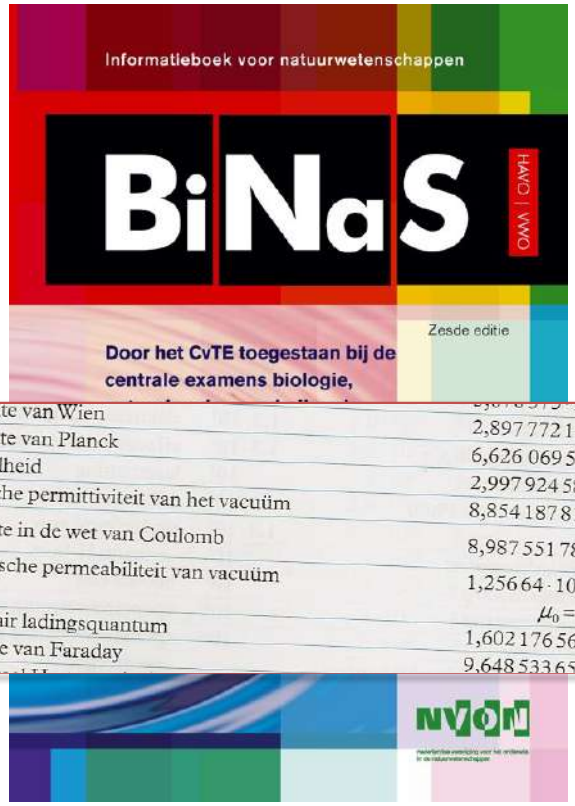


From May 20, 2019

(Convention du Mètre: Paris May 20, 1875)

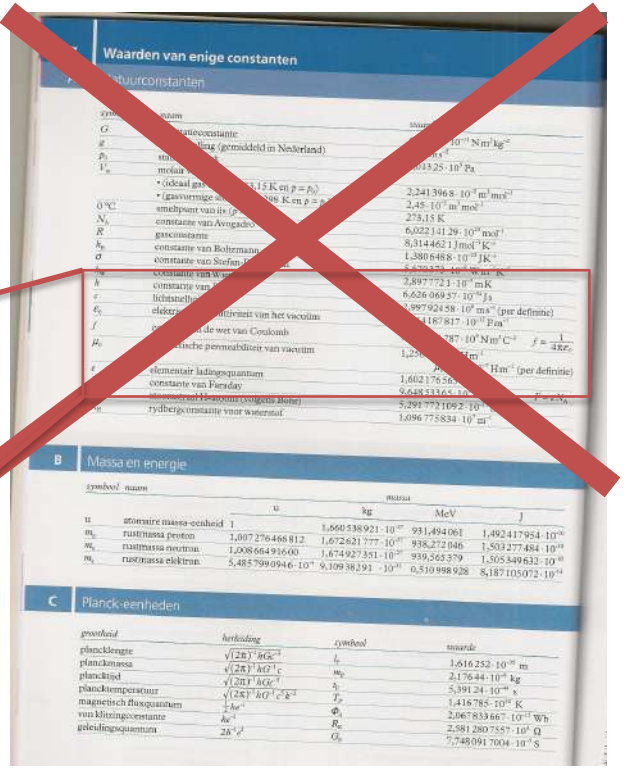
(21 novembre 2019)

SI in BINAS

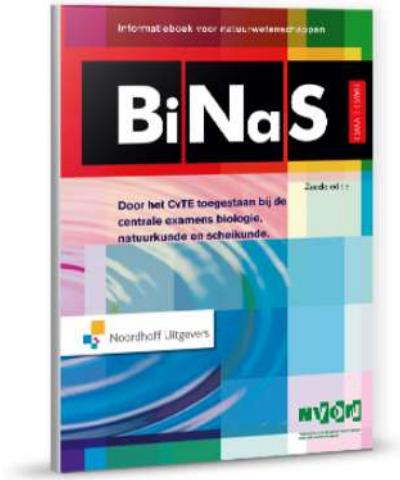


λ_w	constante van Wien	$2{,}897\,7721 \cdot 10^{-3}\ \mathrm{m\,K}$
h	constante van Planck	$6{,}626\,069\,57 \cdot 10^{-34}\ \mathrm{J\,s}$
c	lichtsnelheid	$2{,}997\,924\,58 \cdot 10^{8}\ \mathrm{m\,s^{-1}}$ (per definitie)
ε_0	elektrische permittiviteit van het vacuüm	$8{,}854\,187\,817 \cdot 10^{-12}\ \mathrm{F\,m^{-1}}$
f	constante in de wet van Coulomb	$8{,}987\,551\,787 \cdot 10^{9}\ \mathrm{N\,m^2\,C^{-2}}$ $\quad f = \frac{1}{4\pi\varepsilon_0}$
μ_0	magnetische permeabiliteit van vacuüm	$1{,}256\,64 \cdot 10^{-6}\ \mathrm{H\,m^{-1}}$
		$\mu_0 = 4\pi \cdot 10^{-7}\ \mathrm{H\,m^{-1}}$ (per definitie)
e	elementair ladingsquantum	$1{,}602\,176\,565 \cdot 10^{-19}\ \mathrm{C}$
F	constante van Faraday	$9{,}648\,533\,65 \cdot 10^{4}\ \mathrm{C\,mol^{-1}}$

Tabel 7A (de eerste natuurkunde tabel):



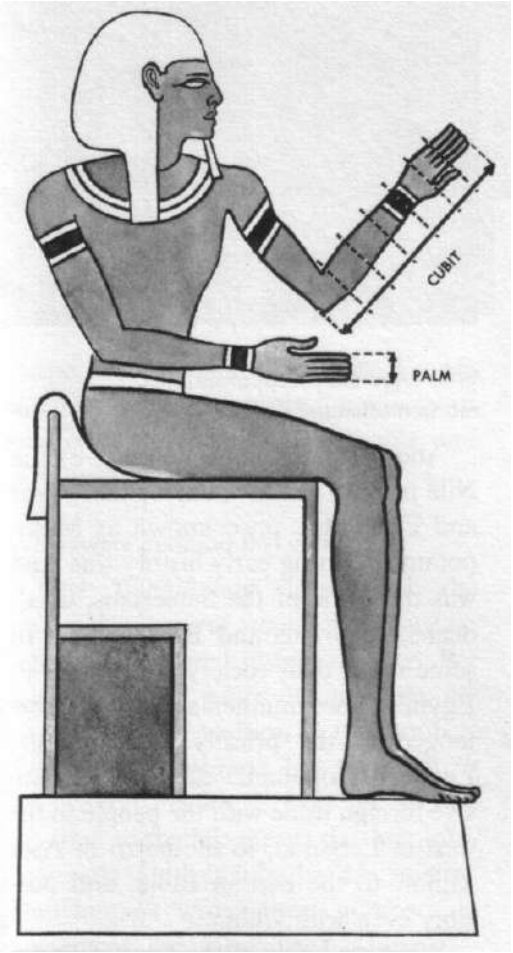
Meten, maten en eenheden

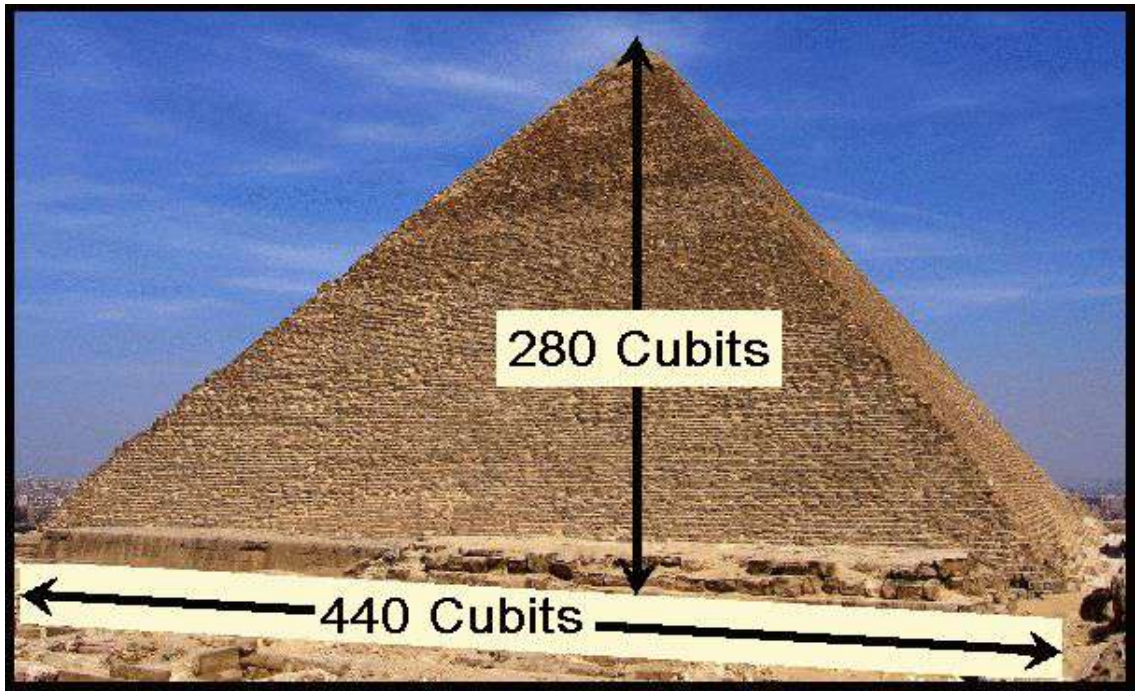


- *Meten is weten*
- *Precisie is van belang, ook in de praktijk*

Hoe meet je eigenlijk? ….

Early length standard





Length standard 1893-1960: Pt:Ir bar

International prototype metre

Closeup of National Prototype Metre Bar No. 27, made in 1889 by the International Bureau of Weights and Measures (BIPM) and given to the United States, which served as the standard for defining all units of length in the US from 1893 to 1960

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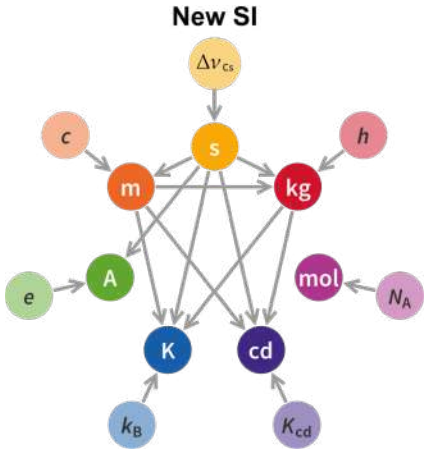
SI: Système Internationale



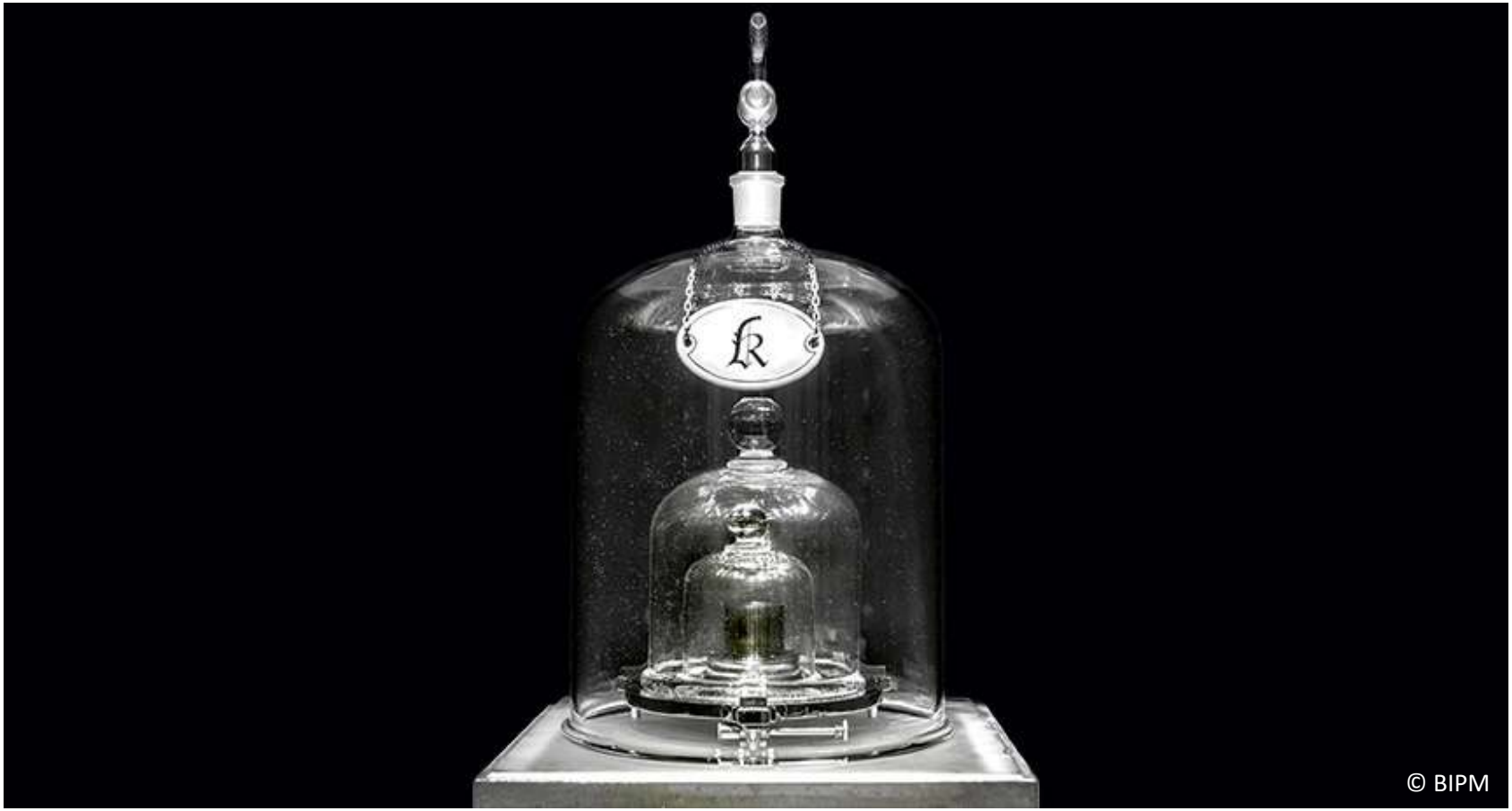
Time (since 1967): $\Delta\nu_{\mathrm{Cs}} \equiv 9\,192\,631\,770\,\mathrm{Hz}$

Cesium atomic clock (ground-state hyperfine transition frequency) as primary time standard

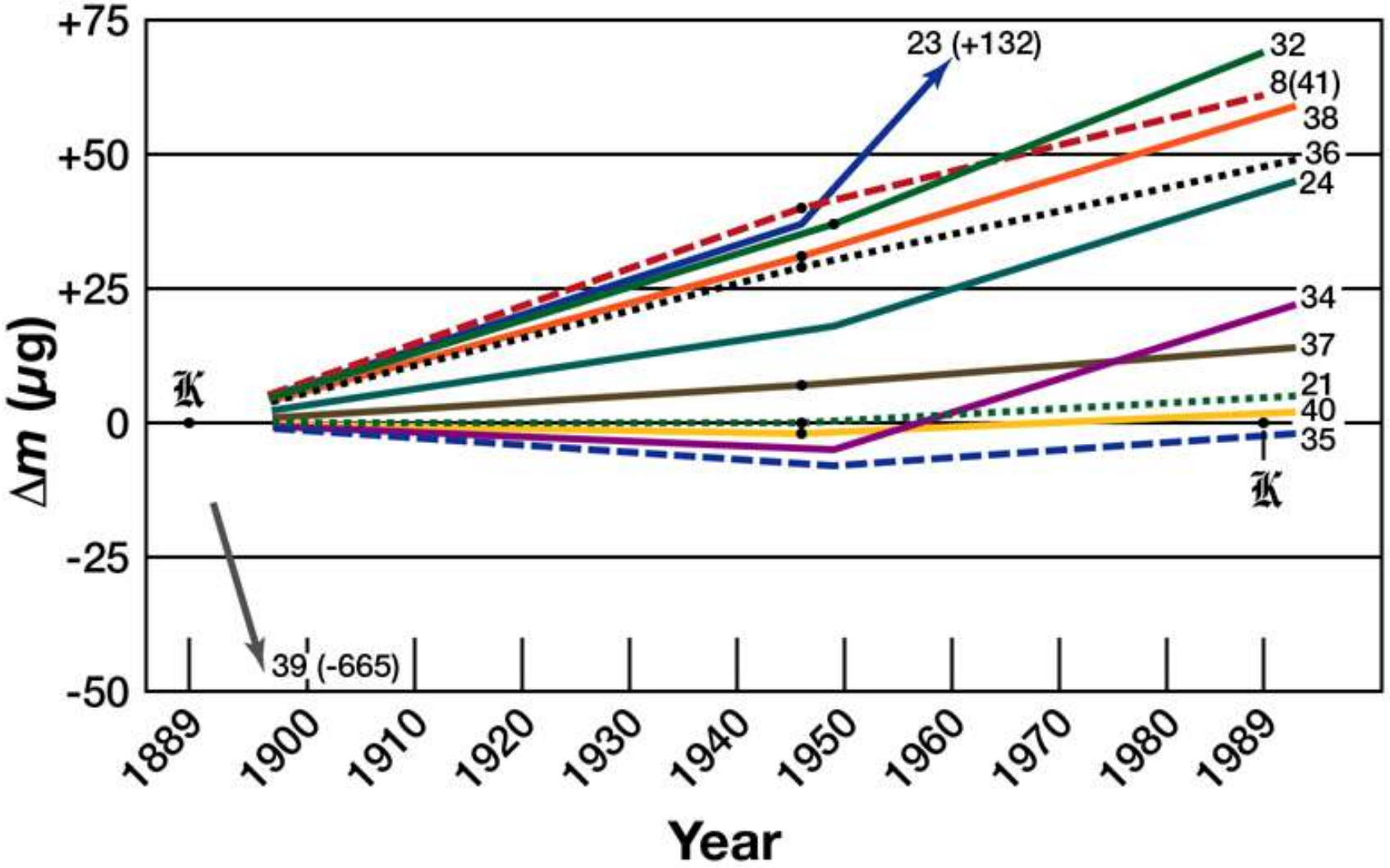
Length (since 1983): $c \equiv 299\,792\,458\,\mathrm{m/s}$

Mass: since 1889:

Le Grand K (1889-2019)

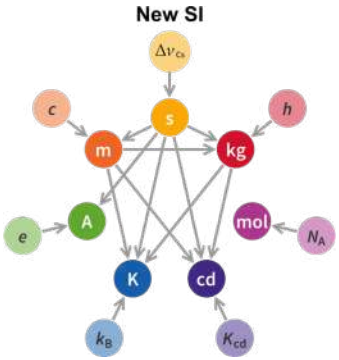


Relative drift of mass standards



Metrologica 31, 317 (1994)

The defining constants of the new SI



$$\Delta\nu_{\mathrm{Cs}} \equiv 9\,192\,631\,770\,\mathrm{Hz}$$

$$c \equiv 299\,792\,458\,\mathrm{m/s}$$

$$h \equiv 6.626\,070\,15 \times 10^{-34}\,\mathrm{Js}$$

$$e \equiv 1.602\,176\,634 \times 10^{-19}\,\mathrm{C}$$

$$k \equiv 1.380\,649 \times 10^{-23}\,\mathrm{J/K}$$

$$N_A \equiv 6.022\,140\,76 \times 10^{23}\,\mathrm{mol}^{-1}$$

$$K_{\mathrm{cd}} \equiv 683\,\mathrm{lm/W}$$

http://physics.nist.gov/constants

Josephson voltage standard

- AC Josephson effect: $V = \frac{h\nu}{2e}$

(voltage across a tunneling junction,
an insulator between two superconductors)

- Josephson constant: $K_J = \frac{2e}{h}$

- Since 1990: $K_{\text{J-90}} \equiv 483\,597.9\,\text{GHz/V}$

- New SI: $K_J \equiv 483\,597.848\,4\ldots\,\text{GHz/V}$

Quantum Hall effect as a reference

- Integer quantum Hall effect:

(Hall conductance of 2DEG in strong magnetic field)

$$\sigma = \frac{I_{\mathrm{channel}}}{V_{\mathrm{Hall}}} = n\frac{e^2}{h}$$

- Von Klitzing constant: $R_K = \dfrac{h}{e^2}$

- Since 1990: $R_{\mathrm{K\text{-}90}} \equiv 25\,812.807\,\Omega$

- New SI: $R_K \equiv 25\,812.807\,45\ldots\Omega$

The electromagnetic constants

Maxwell: $$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

Old SI: $$c \equiv 299\,792\,458\,\mathrm{m/s}$$

$$\mu_0 \equiv 4\pi \times 10^{-7}\,\mathrm{N/A^2}$$

$$\Rightarrow \epsilon_0 \equiv 8.854\ldots \times 10^{-12}\,\mathrm{F/m}$$

The electromagnetic constants

Maxwell: $c = \dfrac{1}{\sqrt{\epsilon_0 \mu_0}}$

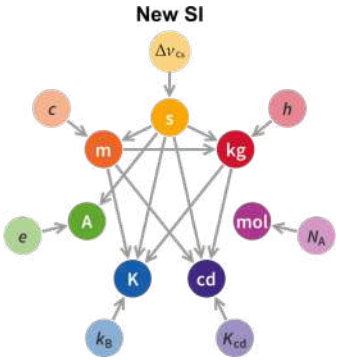
New SI: *e, h, c defined*

$$\epsilon_0 \equiv \frac{e^2}{2\alpha}\frac{1}{hc} = 8.854\,187\,8128(13) \times 10^{-12}\,\mathrm{F/m}$$

$$\Rightarrow \mu_0 = 1.256\,637\,062\,12(19) \times 10^{-6}\,\mathrm{N/A^2}$$

$$4\pi \times 10^{-7} = 1.256\,637\,061\,435\ldots \times 10^{-6}$$

The defining constants of the new SI



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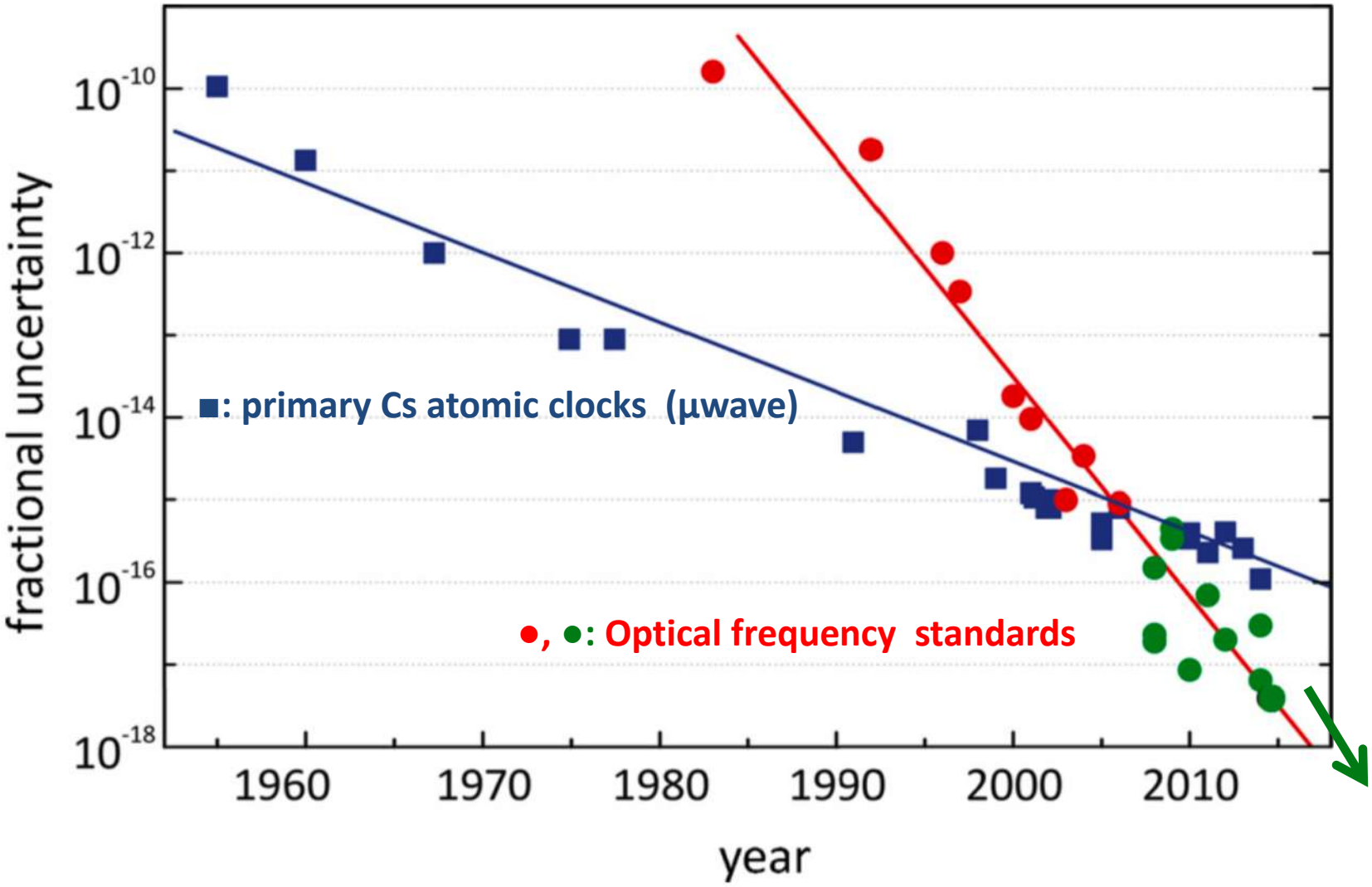
$$K_{\mathrm{cd}} \equiv 683\,\mathrm{lm/W}$$

http://physics.nist.gov/constants

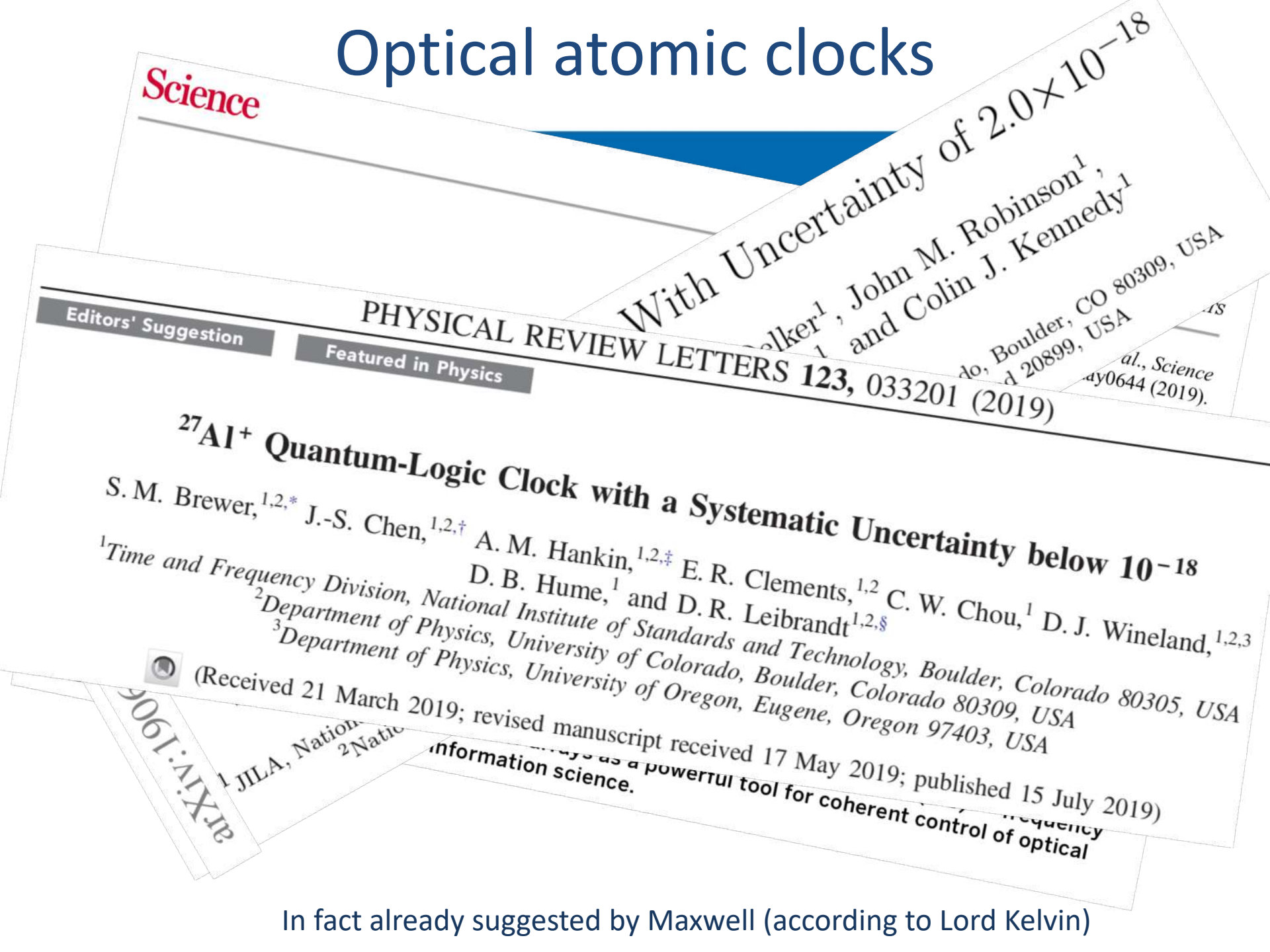
A tous les temps, à tous les peuples

Progress in atomic clocks



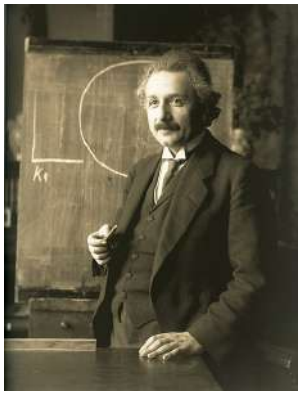
C. R. Phys. 16, 506 (2015)

Optical atomic clocks



In fact already suggested by Maxwell (according to Lord Kelvin)

Gravitational redshift



- Equivalence principle:

locally, gravitational field equivalent to acceleration

- Gravitational redshift:

$$\frac{\Delta\nu}{\nu} = \frac{g\Delta h}{c^2}$$

Numerical value:

$$\frac{g}{c^2} \approx 1.1 \times 10^{-16}\,\mathrm{m}^{-1}$$

iqClock EU quantum flagship consortium

iqclock.eu

StrontiumBEC | About - iqClock

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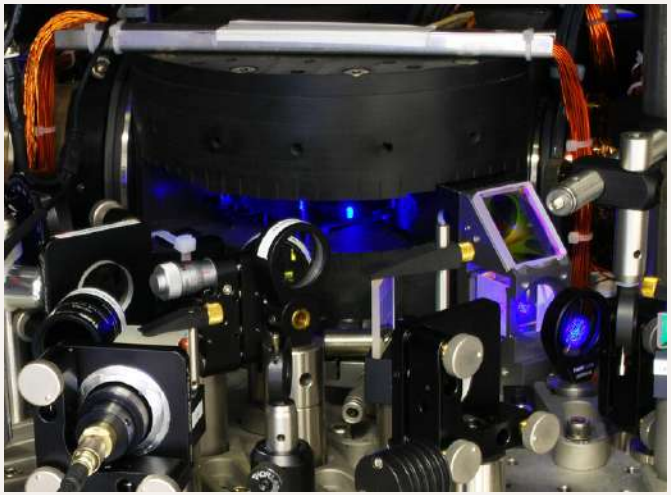
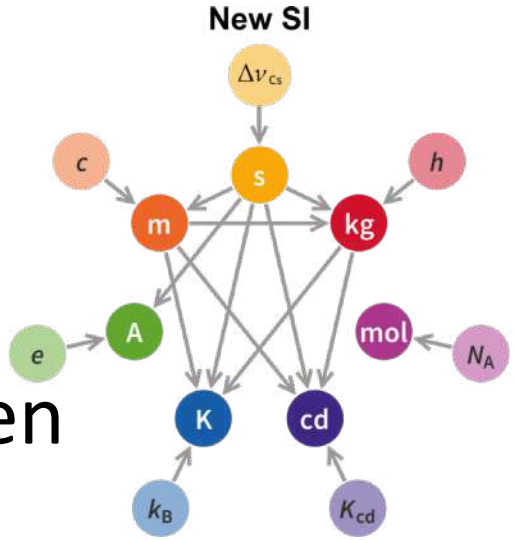
The goal of iqClock



Lab tours!

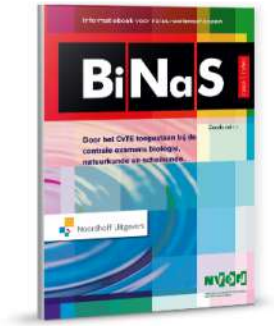
Optical clocks are amazingly stable frequency standards, which would be off by only one second over the age of the universe. Bringing those clocks from the laboratory into a robust and compact form will have a large impact on telecommunication (e.g. network synchronization, traffic bandwidth, GPS free

Samenvattend



Nieuwe SI (sinds 20 mei 2019)

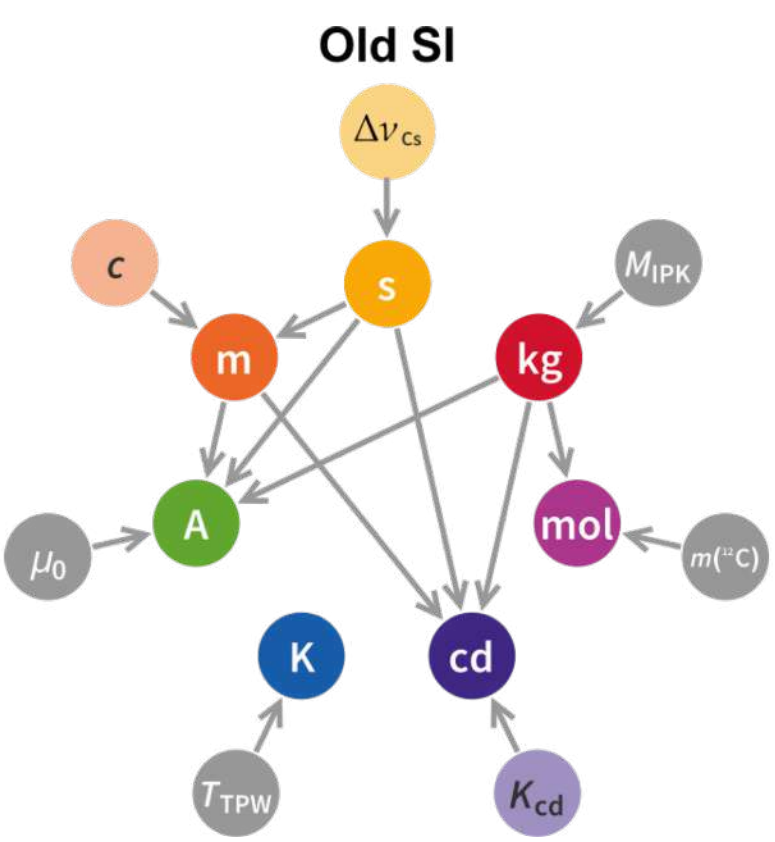
- Gebaseerd op natuurconstanten
- Nieuwe methoden en verschijnselen
- Praktischer en preciezer
- BINAS moet herzien worden



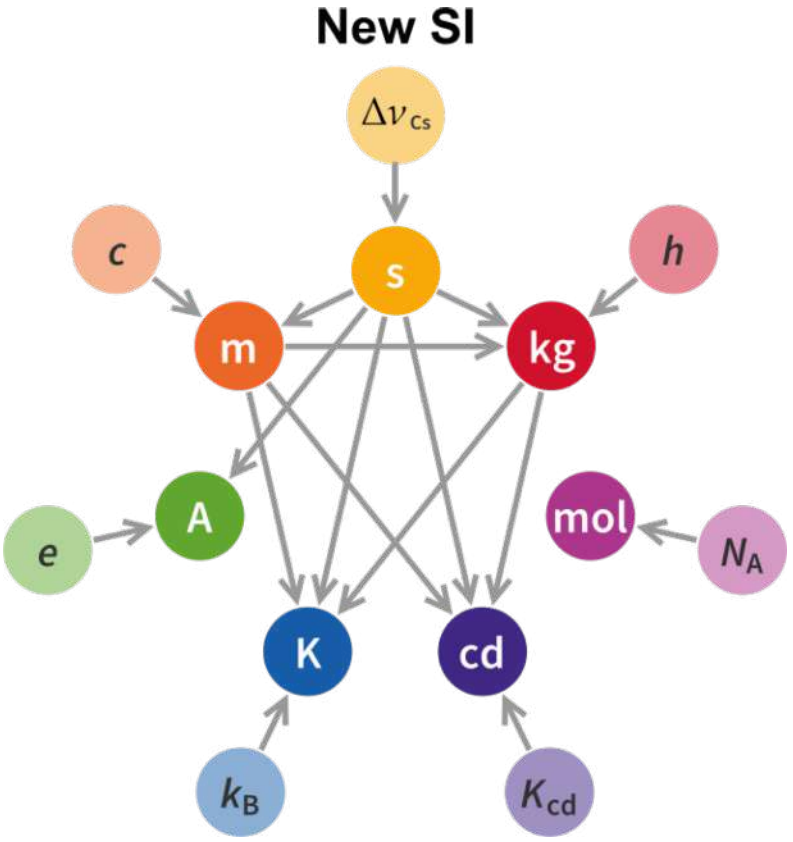
De toekomst van ‘tijd’:

- Verschillende (optische) atoomklokken in de race
- De tijd zal het leren….

Vragen?



1983-2019



May 20, 2019

Links

- Nieuwe SI:
  - https://en.wikipedia.org/wiki/2019_redefinition_of_the_SI_base_units
  - IUPAP Public Session (ICAP 2018)
    https://youtu.be/JsAPW27CeVY

- Nieuwste waarden van natuurconstantes:
  - http://physics.nist.gov/constants

- Sr bij UvA:
  - www.strontiumbec.com
  - http://iop.uva.nl/qgqi (en lab tours!)

- Precieze metingen bij VU:
  - http://www.nat.vu.nl/en/research/atoms_molecules_lasers/index.aspx

- iqClock (EU project geleid door UvA):
  - www.iqClock.eu
  - Folia: https://youtu.be/ryV922Jfqbg