Second: The unit of time

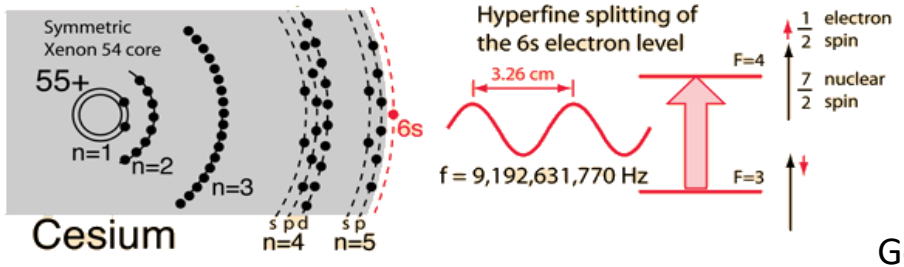
Piyaphat Phoonthong

Definition of Second

- On 13 October 1967, the 13th CGPM adopted the definition of the second, based on an atomic transition in Resolution 1.

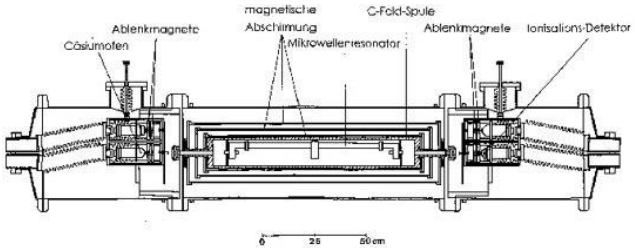
> The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom

- Resolution 2 considered that there were good perspectives for realizing other frequency standards of better quality than the cesium to define the second.

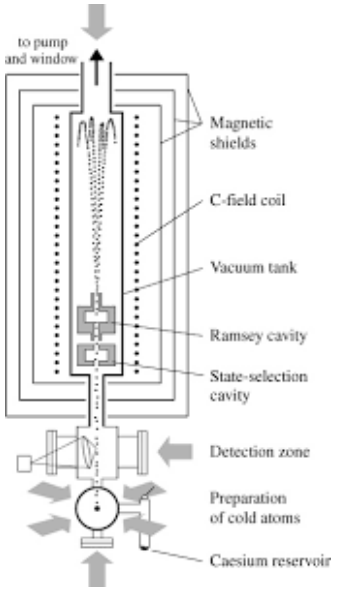


Realization of Second

- The first generation of atomic clock reached the accuracy level of 10^{-14}.



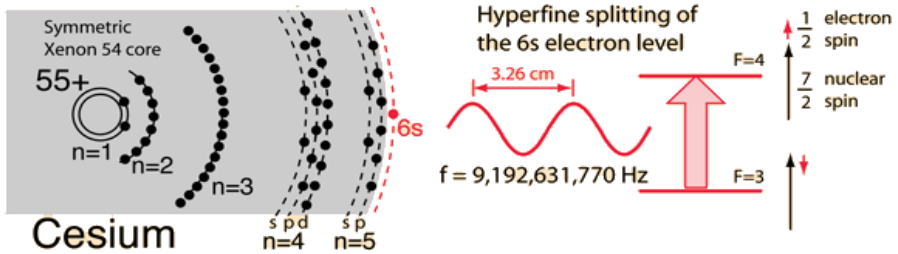
- The Cs fountains, started at the end of the 1990s has now reached accuracy of 10^{-16}.

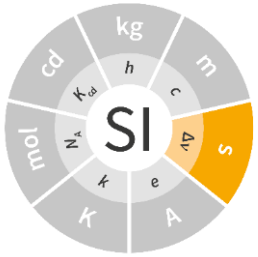


Definition of Second (2019)

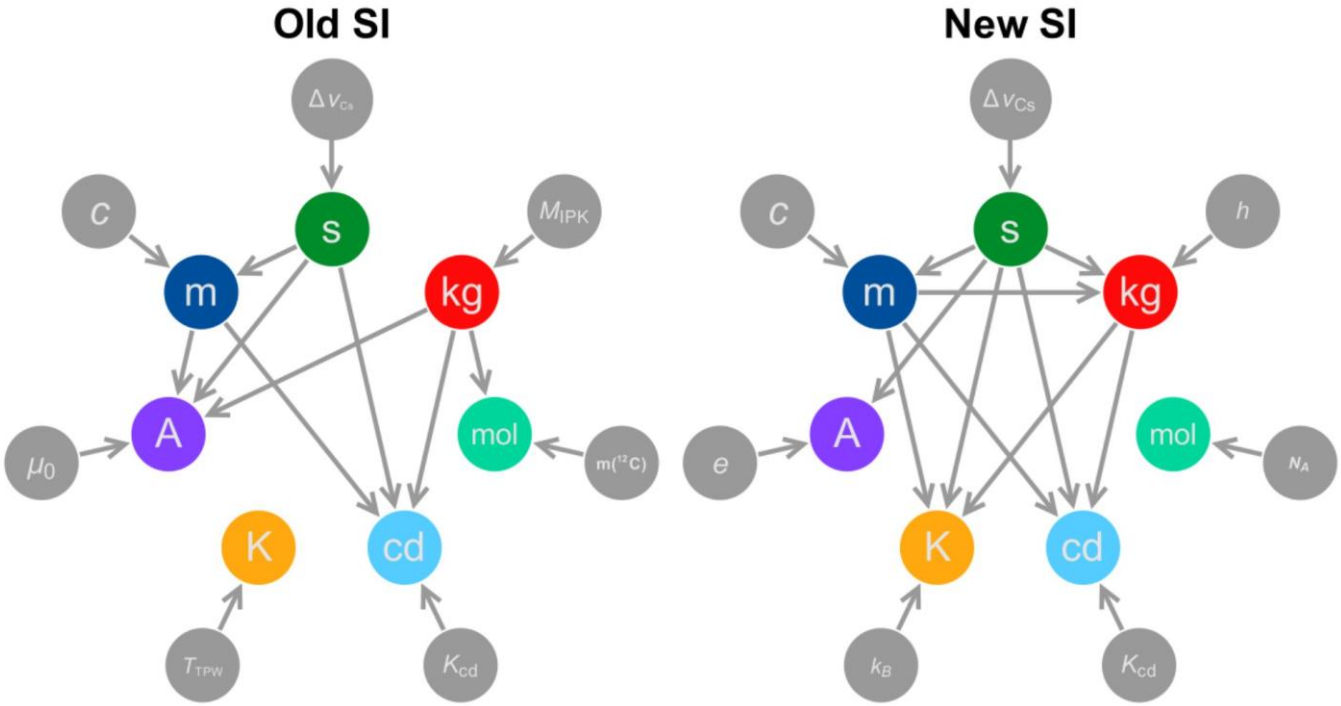
- On 16 November 2018, the 26th CGPM revised the definition of the second, based on the fixed numerical value in Resolution 1.

> The second, symbol s, is the SI unit of time. It is defined by taking the fixed numerical value of the caesium frequency Cs, the unperturbed ground-state hyperfine transition frequency of the caesium-133 atom, to be 9 192 631 770 when expressed in the unit Hz, which is equal to s^{-1}.





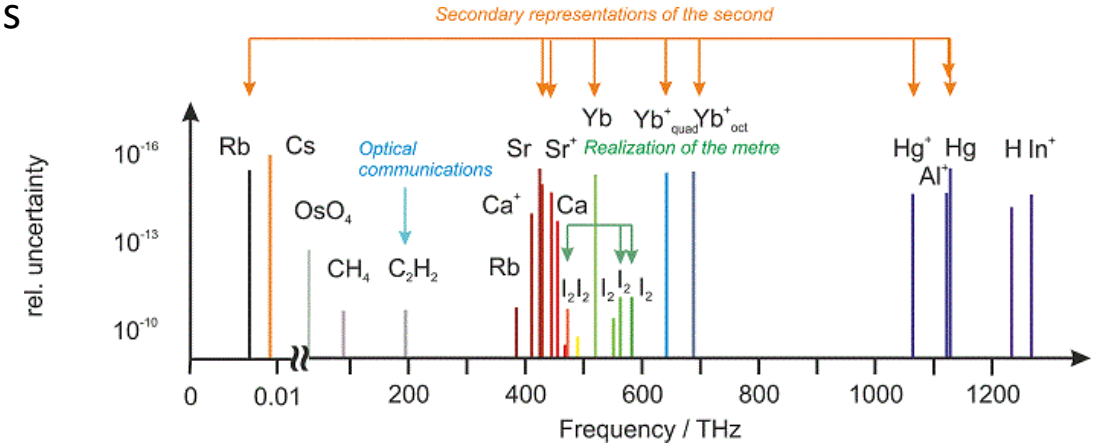
Definition of Second (2019)

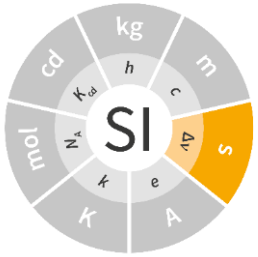


Impacts on time and frequency

Practical Realization

- Atomic Clock
  - Primary Frequency Standard (PFS)
  - Secondary Representations of the Second (SRS)
  - Other Frequency Standards
- Clock Comparisons (GNSS)
- Time Scales (UTC generation)

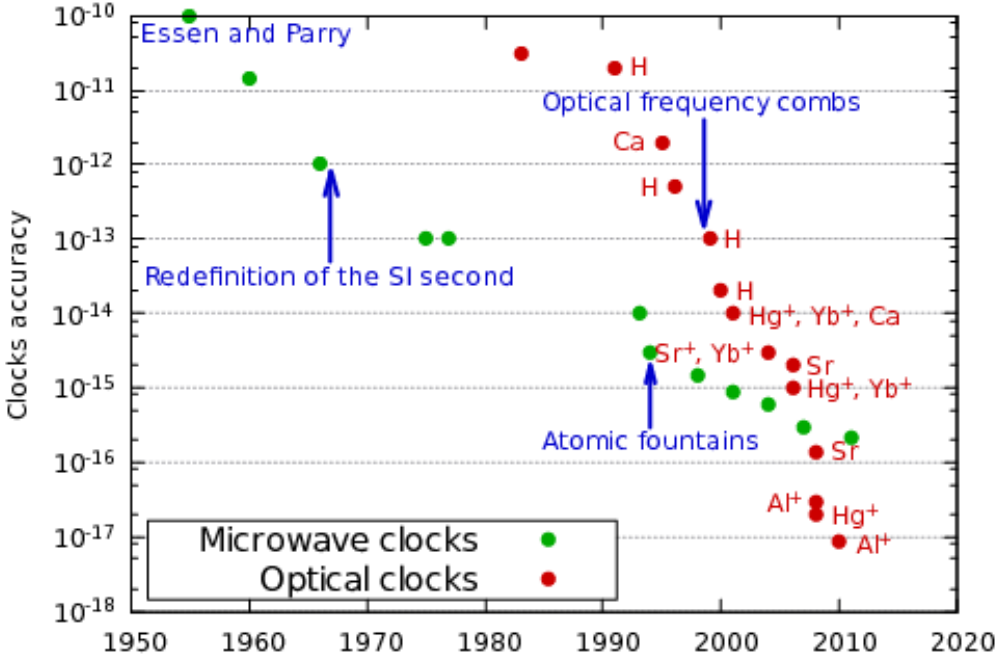




Secondary Representations of the Second

Atom/Ion	Value (Hz)	Uncertainty
^{199}Hg	1 128 575 290 808 154.4 (CCTF 2017)	5E-16
$^{27}Al^{+}$	1 121 015 393 207 857.3 (CIPM 2013)	1.9E-15
$^{199}Hg^{+}$	1 064 721 609 899 145.3 (CIPM 2013)	1.9E-15
$^{171}Yb^{+}$	688 358 979 309 308.3 (CIPM 2015)	6E-16
$^{171}Yb^{+}$	642 121 496 772 645.0 (CIPM 2015)	6E-16
^{171}Yb	518 295 836 590 863.6 (CCTF 2017)	5E-16
$^{88}Sr^{+}$	444 779 044 095 486.5 (CCTF 2017)	1.5E-15
^{88}Sr	429 228 004 229 873.0 (CCTF 2017)	4E-16

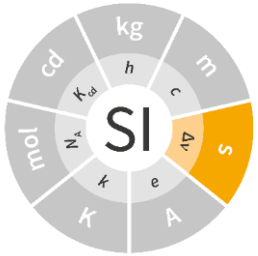
Redefinition of Second



Quantum Projection Noise

$$\sigma(\tau) = \frac{\Delta\nu}{\nu_0}\frac{1}{\sqrt{N}}\sqrt{\frac{T_c}{\tau}}$$

Delva, Pacôme et al. arXiv:1308.6766



Redefinition of Second

- 3 optical clocks have demonstrated validated uncertainties of about 2 orders of magnitude better than the best Cs (few 10^{-18}).
- 3 independent measurements were compared in different institutes ($< 5\times10^{-18}$).
- 3 independent measurements of the optical clock with 3 independent Cs primary clock were performed ($< 3\times10^{-16}$).
- Optical clock contribute regularly to TAI.
- Optical clock ratios have been performed; each ratio was compared ($< 5\times10^{-18}$).

Redefinition of Second

Optical Clock
~10^{-18}

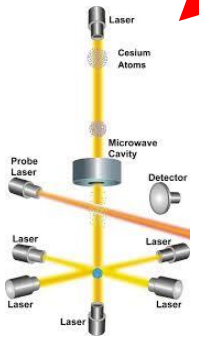
Frequency Comparison/Ratio
10^{-19} - 10^{-21}

Optical Clock
~10^{-18}

Direct Comparison
10^{-17} - 10^{-18}

Optical Fiber link
10^{-19} - 10^{-21}

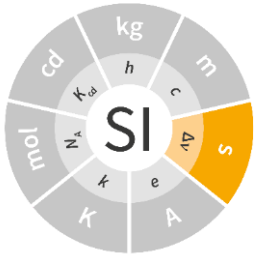
Transportable Clock
10^{-18}



Cs Fountain
~10^{-16}

Satellite Link
10^{-15} - 10^{-17}

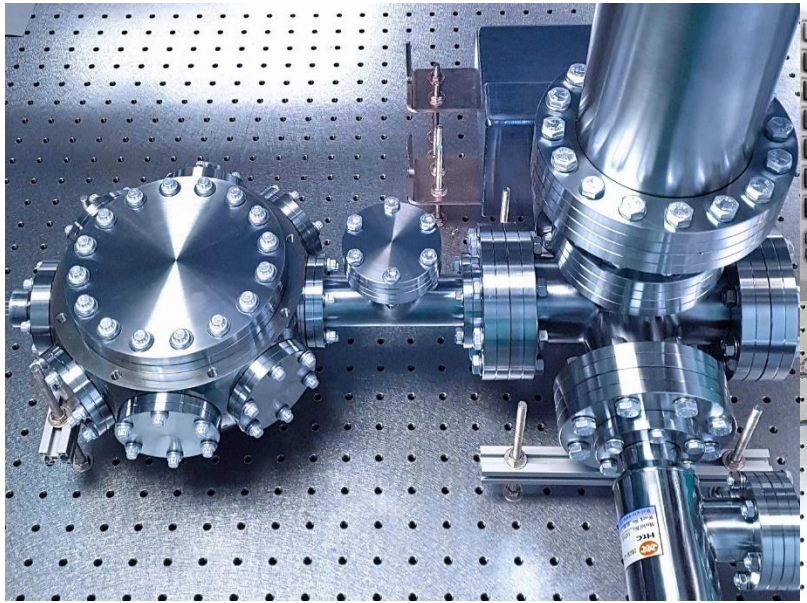
Remote site
Optical Clock
~10^{-18}

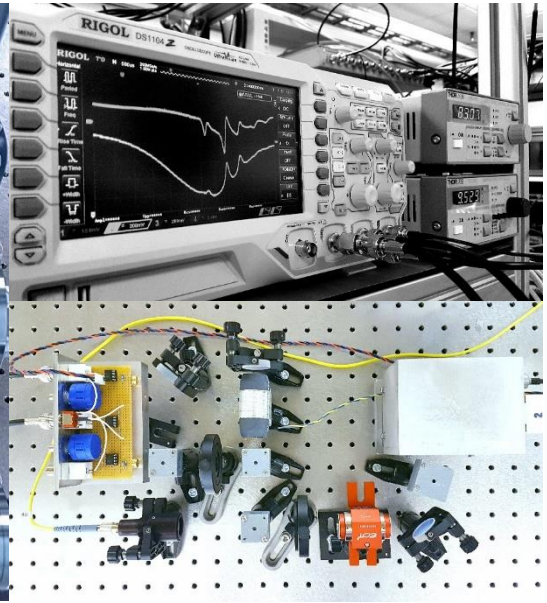


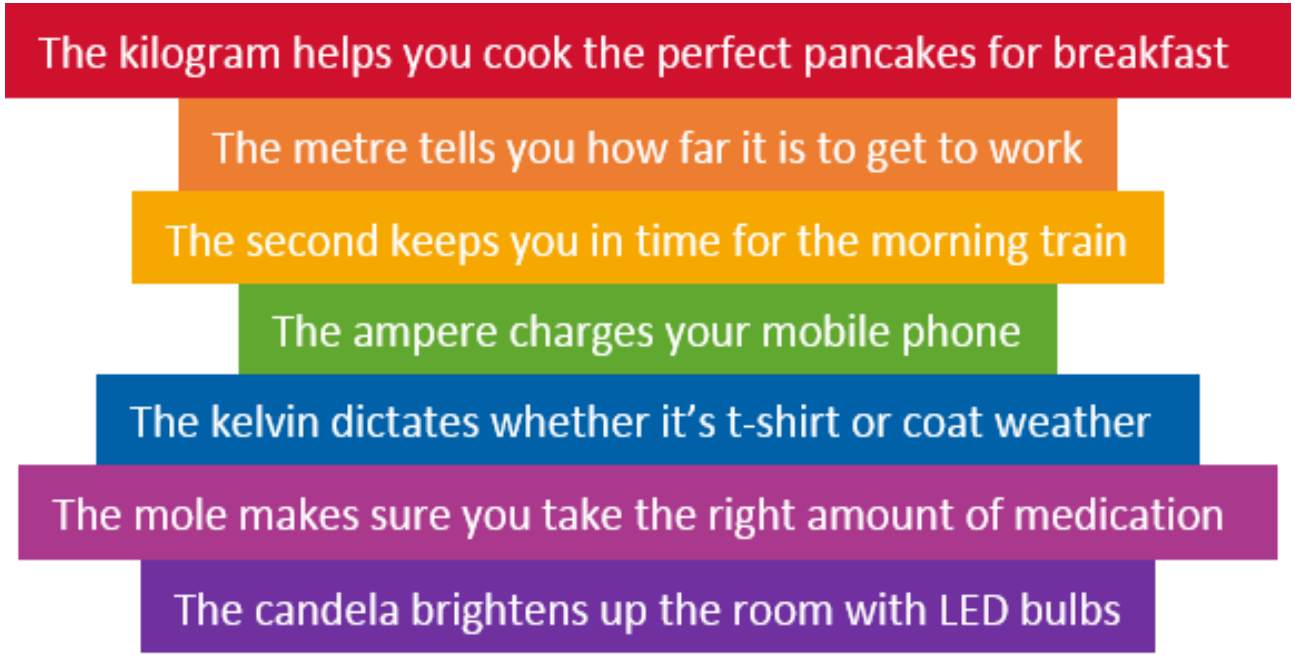
Redefinition of Second

A new definition should therefore take place
as early as possible and as late as necessary

Ytterbium Ion Clock






The kilogram helps you cook the perfect pancakes for breakfast
The metre tells you how far it is to get to work
The second keeps you in time for the morning train
The ampere charges your mobile phone
The kelvin dictates whether it's t-shirt or coat weather
The mole makes sure you take the right amount of medication
The candela brightens up the room with LED bulbs