Second

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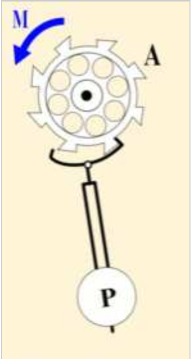

animation showing a pendulum of a clock, ticking every second

The **second** (symbol: **s**) is the base unit of time in the International System of Units (SI)[1] and is also a unit of time in other systems of measurement (abbreviated **s** or **sec**[2]); it is the second division of the hour by sixty, the first division by 60 being the minute.[3] Between 1000 CE (when al-Biruni used seconds) and 1960 the second was defined as 1/86,400 of a mean solar day (that definition still applies in some astronomical and legal contexts).[4][5] Between 1960 and 1967, it was defined in terms of the period of the Earth's orbit around the Sun in 1900,[6] but it is now defined more precisely in atomic terms. Seconds may be measured using mechanical, electric or atomic clocks.

Astronomical observations of the 19th and 20th centuries revealed that the mean solar day is slowly but measurably lengthening and the length of a tropical year is not entirely predictable either; thus the sun–earth motion is no longer considered a suitable basis for definition. With the advent of atomic clocks, it became feasible to define the second based on fundamental properties of nature. Since 1967, the second has been defined to be:

> 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 caesium 133 atom.[1]

In 1997, the CIPM affirmed that the preceding definition "refers to a caesium atom at rest at a temperature of 0 K."[1]

SI prefixes are frequently combined with the word *second* to denote subdivisions of the second, *e.g.*, the millisecond (one thousandth of a second), the microsecond (one millionth of a second), and the nanosecond (one billionth of a second). Though SI prefixes may also be used to form multiples of the second such as kilosecond (one thousand seconds), such units are rarely used in practice. The more common larger non-SI units of time are not formed by powers of ten; instead, the second is multiplied by 60 to form a minute, which is multiplied by 60 to form an hour, which is multiplied by 24 to form a day.

The second is also the base unit of time in the centimetre-gram-second, metre-kilogram-second, metre-tonne-second, and foot-pound-second systems of units.

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International second

Under the International System of Units (via the International Committee for Weights and Measures, or CIPM), since 1967 the second has been defined as 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 caesium 133 atom.[1] In 1997 CIPM added that the periods would be defined for a caesium atom at rest, and approaching the theoretical temperature of absolute zero (0 K), and in 1999, it included corrections from ambient radiation.[1] Absolute zero implies no movement, and therefore zero external radiation effects (i.e., zero local electric and magnetic fields).

The second thus defined is consistent with the ephemeris second, which was based on astronomical measurements. (See History below.) The realization of the standard second is described briefly in a special publication from the National Institute of Standards and Technology,[7] and in detail by the National Research Council of Canada.[8]

Equivalence to other units of time

1 international second is equal to:

- 1/60 minute (but see also leap second)
- 1/3,600 hour
- 1/86,400 day (IAU system of units)
- 1/31,557,600 Julian year (IAU system of units)
- 1/(1 hertz); more generally, (period of wave in seconds)=1/(frequency of wave in hertz), where (period of wave)*(wavenumber)=1/(velocity of wave) in seconds/metre {SI} or in kayser-seconds {CGS}.

History

Before mechanical clocks

The Egyptians subdivided daytime and nighttime into twelve hours each since at least 2000 BC, hence the seasonal variation of their hours. The Hellenistic astronomers Hipparchus (*c*. 150 BC) and Ptolemy (*c*. AD 150) subdivided the day sexagesimally and also used a mean hour ($^1\!/_{24}$ day), simple fractions of an hour ($^1\!/_4$, $^2\!/_3$, etc.) and time-degrees ($^1\!/_{360}$ day or four modern minutes), but not modern minutes or seconds.[9]

The day was subdivided sexagesimally, that is by $^1\!/_{60}$, by $^1\!/_{60}$ of that, by $^1\!/_{60}$ of that, etc., to at least six places after the sexagesimal point (a precision of better than 2 microseconds) by the Babylonians after 300 BC. For example, six fractional sexagesimal places of a day was used in their specification of the length of the year, although they were unable to measure such a small fraction of a day in real time. As another example, they specified that the mean synodic month was 29;31,50,8,20 days (four fractional sexagesimal positions), which was repeated by Hipparchus and Ptolemy sexagesimally, and is currently the mean synodic month of the Hebrew calendar, though restated as 29 days 12 hours 793 halakim (where 1 hour = 1080 halakim).[10] The Babylonians did not use the hour, but did use a double-hour lasting 120 modern minutes, a time-degree lasting four modern minutes, and a barleycorn lasting $3^1\!/_3$ modern seconds (the *helek* of the modern Hebrew calendar),[11] but did not sexagesimally subdivide these smaller units of time. No sexagesimal unit of the day was ever used as an independent unit of time.

In 1000, the Persian scholar al-Biruni gave the times of the new moons of specific weeks as a number of days, hours, minutes, seconds, thirds, and fourths after noon Sunday.[5] In 1267, the medieval scientist Roger Bacon stated the times of full moons as a number of hours, minutes, seconds, thirds, and fourths (*horae*, *minuta*, *secunda*, *tertia*, and *quarta*) after noon on specified calendar dates.[12] Although a *third* for $^1\!/_{60}$ of a second remains in some languages, for example Polish (*tercja*) and Turkish (*salise*), the modern second is subdivided decimally.

Seconds measured by mechanical clocks

The earliest clocks to display seconds appeared during the last half of the 16th century. The earliest spring-driven timepiece with a second hand which marked seconds is an unsigned clock depicting Orpheus in the Fremersdorf collection, dated between 1560 and 1570.[13]:417–418[14] During the 3rd quarter of the 16th century, Taqi al-Din built a clock with marks every 1/5 minute.[15] In 1579, Jost Bürgi built a clock for William of Hesse that marked seconds.[13]:105 In 1581, Tycho Brahe redesigned clocks that displayed minutes at his observatory so they also displayed seconds. However, they were not yet accurate enough for seconds. In 1587, Tycho complained that his four clocks disagreed by plus or minus four seconds.[13]:104

The second first became accurately measurable with the development of pendulum clocks keeping *mean time* (as opposed to the *apparent time* displayed by sundials). In 1644, Marin Mersenne calculated that a pendulum with a length of 39.1 inches (0.994 m) would have a period at one standard gravity of precisely two seconds, one second for a swing forward and one second for the return swing, enabling such a pendulum to tick in precise seconds.

In 1670, London clockmaker William Clement added this seconds pendulum to the original pendulum clock of Christiaan Huygens.[16] From 1670 to 1680, Clement made many improvements to his clock and introduced the longcase or grandfather clock to the public. This clock used an anchor escapement mechanism with a seconds pendulum to display seconds in a small subdial. This mechanism required less power, caused less friction and was accurate enough to measure seconds reliably as one-sixtieth of a minute than the older verge escapement. Within a few years, most British precision clockmakers were producing longcase clocks and other clockmakers soon followed. Thus the second could now be reliably measured.

Modern measurements

As a unit of time, the second (meaning the *second* division by 60 of an hour) entered English in the late 16th century, about a hundred years before it was measured accurately. Those who wrote in Latin, including scientists like Bacon, Tycho and Kepler, used the Latin term *secunda* with the same meaning as far back as the 1200s.

In 1832, Gauss proposed using the second as the base unit of time in his millimeter-milligram-second system of units. The British Association for the Advancement of Science (BAAS) in 1862 stated that "All men of science are agreed to use the second of mean solar time as the unit of time."[17] BAAS formally proposed the CGS system in 1874, although this system was gradually replaced over the next 70 years by MKS units. Both the CGS and MKS systems used the same second as their base unit of time. MKS was adopted internationally during the 1940s, defining the second as 1/86,400th of a mean solar day.

In 1956, the second was redefined in terms of a *year* (the period of the Earth's revolution around the Sun) *for a particular epoch* because, by then, it had become recognized that the Earth's rotation on its own axis was not sufficiently uniform as a standard of time. The Earth's motion was described in Newcomb's Tables of the Sun (1895), which provided a formula for estimating the motion of the Sun relative to the epoch 1900 based on astronomical observations made between 1750 and 1892.[6]

The second was thus defined as:

> the fraction 1/31,556,925.9747 of the tropical year for 1900 January 0 at 12 hours ephemeris time.[6]

This definition was ratified by the Eleventh General Conference on Weights and Measures in 1960, which also established the International System of Units.

The *tropical year* in the 1960 definition was not measured but calculated from a formula describing a mean tropical year that decreased linearly over time, hence the curious reference to a specific *instantaneous* tropical year. This was in conformity with the ephemeris time scale adopted by the IAU in 1952.[18] This definition brings the observed positions of the celestial bodies into accord with Newtonian dynamical theories of their motion. Specifically, those tables used for most of the 20th century were Newcomb's Tables of the Sun (used from 1900 through 1983) and Brown's Tables of the Moon (used from 1923 through 1983).[6]

Thus, the 1960 SI definition abandoned any explicit relationship between the scientific second and the length of a day, as most people understand the term. With the development of the atomic clock in the early 1960s, it was decided to use atomic time as the basis of the definition of the second, rather than the revolution of the Earth around the Sun.

Following several years of work, Louis Essen from the National Physical Laboratory (Teddington, England) and William Markowitz from the United States Naval Observatory (USNO) determined the relationship between the hyperfine transition frequency of the caesium atom and the ephemeris second.[6][19] Using a common-view measurement method based on the received signals from radio station WWV,[20] they determined the orbital motion of the Moon about the Earth, from which the apparent motion of the Sun could be inferred, in terms of time as measured by an atomic clock. They found that the second of ephemeris time (ET) had the duration of 9,192,631,770 ± 20 cycles of the chosen caesium frequency.[19] As a result, in 1967 the *Thirteenth General Conference on Weights and Measures* defined the SI second of atomic time as:

> 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 caesium-133 atom.[6]

FOCS 1, a continuous cold caesium fountain atomic clock in Switzerland, started operating in 2004 at an uncertainty of one second in 30 million years.

This SI second, referred to atomic time, was later verified to be in agreement, within 1 part in 10^{10}, with the second of ephemeris time as determined from lunar observations.[21] (Nevertheless, this SI second was already, when adopted, a little shorter than the then-current value of the second of mean solar time.[22][23])

During the 1970s it was realized that gravitational time dilation caused the second produced by each atomic clock to differ depending on its altitude. A uniform second was produced by correcting the output of each atomic clock to mean sea level (the rotating geoid), lengthening the second by about 1×10^{-10}. This correction was applied at the beginning of 1977 and formalized in 1980. In relativistic terms, the SI second is defined as the proper time on the rotating geoid.[24]

The definition of the second was later refined at the 1997 meeting of the BIPM to include the statement

> This definition refers to a caesium atom at rest at a temperature of 0 K.

The revised definition seems to imply that the ideal atomic clock contains a single caesium atom at rest emitting a single frequency. In practice, however, the definition means that high-precision realizations of the second should compensate for the effects of the ambient temperature (black-body radiation) within which atomic clocks operate, and extrapolate accordingly to the value of the second at a temperature of absolute zero.

Possible future enhancements

Today, the atomic clock operating in the microwave region is challenged by atomic clocks operating in the optical region. To quote Ludlow *et al.*,[25] “In recent years, optical atomic clocks have become increasingly competitive in performance with their microwave counterparts. The overall accuracy of single-trapped-ion-based optical standards closely approaches that of the state-of-the-art caesium fountain standards. Large ensembles of ultracold alkaline earth atoms have provided impressive clock stability for short averaging times, surpassing that of single-ion-based systems. So far, interrogation of neutral-atom-based optical standards has been carried out primarily in free space, unavoidably including atomic motional effects that typically limit the overall system accuracy. An alternative approach is to explore the ultranarrow optical transitions of atoms held in an optical lattice. The atoms are tightly localized so that Doppler and photon-recoil related effects on the transition frequency are eliminated.”

The NRC (http://inms-ienm.nrc-cnrc.gc.ca/research/optical_frequency_projects_e.html#optical) attaches a "relative uncertainty" of 2.5×10^{-11} (limited by day-to-day and device-to-device reproducibility) to their atomic clock based upon the $^{127}I_2$ molecule, and is advocating use of an ^{88}Sr ion trap instead (relative uncertainty due to linewidth of 2.2×10^{-15}). See magneto-optical trap and "Trapped ion optical frequency standards" (http://www.npl.co.uk/server.php?show=ConWebDoc.1086). National Physical Laboratory. Such uncertainties rival that of the NIST-F1 caesium atomic clock in the microwave region, estimated as a few parts in 10^{16} averaged over a day.[26][27]

SI multiples

SI prefixes are commonly used to measure time less than a second, but rarely for multiples of a second (which is known as metric time). Instead, the non-SI units minutes, hours, days, Julian years, Julian centuries, and Julian millennia are used.

SI multiples for second (s)

Submultiples				Multiples		
Value	**Symbol**	**Name**		**Value**	**Symbol**	**Name**
10^{-1} s	ds	decisecond		10^{1} s	das	decasecond
10^{-2} s	cs	centisecond		10^{2} s	hs	hectosecond
10^{-3} s	**ms**	**millisecond**		10^{3} s	ks	kilosecond
10^{-6} s	**µs**	**microsecond**		10^{6} s	Ms	megasecond
10^{-9} s	**ns**	**nanosecond**		10^{9} s	Gs	gigasecond
10^{-12} s	ps	picosecond		10^{12} s	Ts	terasecond
10^{-15} s	fs	femtosecond		10^{15} s	Ps	petasecond
10^{-18} s	as	attosecond		10^{18} s	Es	exasecond
10^{-21} s	zs	zeptosecond		10^{21} s	Zs	zettasecond
10^{-24} s	ys	yoctosecond		10^{24} s	Ys	yottasecond
Common prefixes are in bold						

Other current definitions

For specialized purposes, a second may be used as a unit of time in time scales where the precise length differs slightly from the SI definition. One such time scale is UT1, a form of universal time. McCarthy and Seidelmann refrain from stating that the SI second is the legal standard for timekeeping throughout the world, saying only that "over the years UTC [which ticks SI seconds] has become either the basis for legal time of many countries, or accepted as the *de facto* basis for standard civil time".[28]

See also

- SI unit
- Orders of magnitude (time)
- Becquerel
- Coordinated Universal Time
- Hertz
- International Atomic Time
- International System of Units
- Leap second
- Magneto-optical trap
- Specific impulse
- Time standard
- Femtosecond
- Microsecond
- Millisecond

- Nanosecond
- Picosecond

Notes and references

1. "Unit of time (second)" (http://www.bipm.org/en/si/si_brochure/chapter2/2-1/second.html). *SI Brochure*. BIPM. Retrieved 2013-12-22.
2. "Second" (http://www.learnersdictionary.com/search/sec). Merriam Webster Learner's Dictionary.
3. "Online Etymology Dictionary" (http://www.etymonline.com/index.php?term=second).
4. International System of Units from NIST (http://physics.nist.gov/cuu/Units/second.html) accessed 2012-3-25.
5. al-Biruni (1879). *The chronology of ancient nations: an English version of the Arabic text of the Athâr-ul-Bâkiya of Albîrûnî, or "Vestiges of the Past"* (http://books.google.com/?id=pFIEAAAAIAAJ&pg=PA148#v=onepage&q=). Sachau C Edward. pp. 147–149.
6. "Leap Seconds" (http://tycho.usno.navy.mil/leapsec.html). Time Service Department, United States Naval Observatory. Retrieved 2012-03-24.
7. BN Taylor, A Thompson (Eds.), ed. (2008). "Appendix 2". *The International System of Units (SI)* (http://www.bipm.org/utils/en/pdf/SIApp2_s_en.pdf). NIST Special Publication **330**. pp. 53 ff. Retrieved 2014-08-25.
8. "NRC's Cesium Fountain Clock - FCs1" (http://archive.nrc-cnrc.gc.ca/eng/projects/inms/fountain-clock.html). National Research Council of Canada. Retrieved 2013-11-29.
9. Toomer, G. J. (1998). *Ptolemy's Almagest*. Princeton, New Jersey: Princeton University Press. pp. 6–7, 23, 211–216. ISBN 978-0-691-00260-6.
10. O Neugebauer (1975). *A history of ancient mathematical astronomy*. Springer-Verlag. ISBN 0-387-06995-X.
11. See page 325 in O Neugebauer (1949). "The astronomy of Maimonides and its sources". *Hebrew Union College Annual* **22**: 321–360.
12. R Bacon (2000) [1928]. *The Opus Majus of Roger Bacon*. BR Belle. University of Pennsylvania Press. table facing page 231. ISBN 978-1-85506-856-8.
13. Landes, David S. (1983). *Revolution in Time*. Cambridge, Massachusetts: Harvard University Press. ISBN 0-674-76802-7.
14. Willsberger, Johann (1975). *Clocks & watches*. New York: Dial Press. ISBN 0-8037-4475-7. full page color photo: 4th caption page, 3rd photo thereafter (neither pages nor photos are numbered).
15. Taqi al-Din (http://books.google.com/books?id=raKRY3KQspsC&pg=PA934)
16. Jessica Chappell (Oct 1, 2001). "The Long Case Clock: The Science and Engineering that Goes Into a Grandfather Clock" (http://illumin.usc.edu/184/the-long-case-clock-engineering-behind-a-grandfather-clock/). *Illumin* **1**: 1.
17. Jenkin, ed. (1873). *Reports of the committee on electrical standards* (http://books.google.com/books?id=540DAAAAQAAJ&pg=PR1#v=onepage&q&f=true). British Association for the Advancement of Science. p. 90.
18. *Explanatory Supplement to the Astronomical Ephemeris and the American Ephemeris and Nautical Almanac* (prepared jointly by the Nautical Almanac Offices of the United Kingdom and the United States of America, HMSO, London, 1961), at Sect. 1C, p.9), stating that at a conference "in March 1950 to discuss the fundamental constants of astronomy ... the recommendations with the most far-reaching consequences were those that defined ephemeris time and brought the lunar ephemeris into accordance with the solar ephemeris in terms of ephemeris time. These recommendations were addressed to the International Astronomical Union and were formally adopted by Commission 4 and the General Assembly of the Union in Rome in September 1952."
19. W Markowitz, RG Hall, L Essen, JVL Parry; Hall; Essen; Parry (1958). "Frequency of cesium in terms of ephemeris time" (http://www.leapsecond.com/history/1958-PhysRev-v1-n3-Markowitz-Hall-Essen-Parry.pdf). *Physical Review Letters* **1** (3): 105–107. Bibcode:1958PhRvL...1..105M (http://adsabs.harvard.edu/abs/1958PhRvL...1..105M). doi:10.1103/PhysRevLett.1.105 (https://dx.doi.org/10.1103%2FPhysRevLett.1.105).
20. S Leschiutta (2005). "The definition of the 'atomic' second". *Metrologia* **42** (3): S10–S19. Bibcode:2005Metro..42S..10L (http://adsabs.harvard.edu/abs/2005Metro..42S..10L). doi:10.1088/0026-1394/42/3/S03 (https://dx.doi.org/10.1088%2F0026-1394%2F42%2F3%2FS03).
21. W Markowitz (1988). AK Babcock, GA Wilkins, ed. *The Earth's Rotation and Reference Frames for Geodesy and Geophysics*. IAU Sumposia #128. pp. 413–418. Bibcode:1988IAUS..128..413M (http://adsabs.harvard.edu/abs/1988IAUS..128..413M).
22. DD McCarthy, C Hackman, R Nelson; Hackman; Nelson (2008). "The Physical Basis of the Leap Second". *Astronomical Journal* **136** (5): 1906–1908. Bibcode:2008AJ....136.1906M (http://adsabs.harvard.edu/abs/2008AJ....136.1906M). doi:10.1088/0004-6256/136/5/1906 (https://dx.doi.org/10.1088%2F0004-6256%2F136%2F5%2F1906). "... the SI second is equivalent to an older measure of the second of UT1, which was too small to start with and further, as the duration of the UT1 second increases, the discrepancy widens."
23. In the late 1950s, the caesium standard was used to measure both the current mean length of the second of mean solar time (UT2) (9 192 631 830 cycles) and also the second of ephemeris time (ET) (9 192 631 770 ±20 cycles), see L Essen (1968). "Time Scales" (http://www.leapsecond.com/history/1968-Metrologia-v4-n4-Essen.pdf). *Metrologia* **4** (4): 161–165. Bibcode:1968Metro...4..161E (http://adsabs.harvard.edu/abs/1968Metro...4..161E). doi:10.1088/0026-1394/4/4/003 (https://dx.doi.org/10.1088%2F0026-1394%2F4%2F4%2F003).. As noted in page 162, the 9 192 631 770 figure was chosen for the SI second. L Essen in the same 1968 article stated that this value "seemed reasonable in view of the variations in UT2".

24. See page 515 in RA Nelson et al. (2000). "The leap second: its history and possible future" (http://www.cl.cam.ac.uk/~mgk25/time/metrologia-leapsecond.pdf). *Metrologia* **38** (6): 509–529. Bibcode:2001Metro..38..509N (http://adsabs.harvard.edu/abs/2001Metro..38..509N). doi:10.1088/0026-1394/38/6/6 (https://dx.doi.org/10.1088%2F0026-1394%2F38%2F6%2F6).
25. AD Ludlow et al. (2006). "Systematic study of the ^{87}Sr clock transition in an optical lattice". *Physical Review Letters* **96** (3): 033003. arXiv:physics/0508041 (https://arxiv.org/abs/physics/0508041). Bibcode:2006PhRvL..96c3003L (http://adsabs.harvard.edu/abs/2006PhRvL..96c3003L). doi:10.1103/PhysRevLett.96.033003 (https://dx.doi.org/10.1103%2FPhysRevLett.96.033003).
26. R Wynands, S Weyers; Weyers (2005). "Atomic fountain clocks". *Metrologia* **42** (3): S64–S79. Bibcode:2005Metro..42S..64W (http://adsabs.harvard.edu/abs/2005Metro..42S..64W). doi:10.1088/0026-1394/42/3/S08 (https://dx.doi.org/10.1088%2F0026-1394%2F42%2F3%2FS08).
27. "NIST-F1 Cesium Fountain Atomic Clock" (http://tf.nist.gov/cesium/fountain.htm). NIST. Retrieved 2009-08-19.
28. McCarty, D. D.; Seidelmann, P. K. (2009). *TIME From Earth Rotation to Atomic Physics*. Weinheim: WILEY-VCH Verlag GmbH & Co. pp. 68, 232.

External links

- National Physical Laboratory: *Trapped ion optical frequency standards* (http://www.npl.co.uk/server.php?show=ConWebDoc.1086)
- *High-accuracy strontium ion optical clock*; National Physical Laboratory (2005) (http://resource.npl.co.uk/docs/networks/time/meeting3/klein.pdf)
- National Research Council of Canada: *Optical frequency standard based on a single trapped ion* (http://inms-ienm.nrc-cnrc.gc.ca/research/optical_frequency_projects_e.html#optical)
- NIST: *Definition of the second*; notice the cesium atom must be in its ground state at 0 K (http://physics.nist.gov/cuu/Units/second.html)
- Official BIPM definition of the second (http://www.bipm.org/en/si/si_brochure/chapter2/2-1/second.html)
- The leap second: its history and possible future (http://www.cl.cam.ac.uk/~mgk25/time/metrologia-leapsecond.pdf)
- *What is a Cesium atom clock?* (http://inms-ienm.nrc-cnrc.gc.ca/faq_time_e.html#10)

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