Letters About the IUPAC-IUGS Common Definition and Convention on the Use of the Year as A Derived Unit of Time

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Neither a Year nor an Annus Can Be a Derived Unit in the SI

by Lucy E. Edwards

Recently, a paper appeared in the journal *Pure and Applied Chemistry*, the official publication of the International Union of Pure and Applied Chemistry.[1a] The same paper was published in Episodes,[1b] the official journal of the International Union of Geological Sciences. Entitled "IUPAC-IUGS common definition and convention on the use of the year as a derived unit of time," these papers

1. Propose that the year or annus (a) be defined for the epoch 2000.0 as 1 a = 3.155 692 5445 x 10^7 s.
2. Recommend that geoscientists express time durations as a, ka, Ma, Ga.
3. Suggest that these recommendations further the goal of achieving compliance with the international standard (a specific standard is not specified).

The authors noted "that use of units for time in the geological literature is inconsistent both internally and with respect to SI (*Le Système international d'unités*)." They state that their proposed solution requires "neither new experiments nor extensive literature evaluations but only judgment and adherence to SI rules."[1]

Many readers of *Pure and Applied Chemistry* and of *Episodes* will not have read the latest *The International System of Units* (SI).[2] Here is information pertinent to the recommendations in reference 1.

There are seven base units in the SI: unit of length (metre), unit of mass (kilogram), unit of time (second), unit of electric current (ampere), unit of thermodynamic temperature (kelvin), unit of amount of substance (mole), and unit of luminous intensity (candela).

SI derived units are products of powers of base units. Examples are m^3, which measures volume; m/s, which measures speed, velocity; s^{-1}, which measures frequency.

The year is not a unit of the SI. The only SI unit of measurement for time is the second. The word "annus" or "annum" does not appear anywhere in the current SI document. The word "year" is not in the table of "Non-SI units accepted for use with the International System of Units," nor in the table of "Non-SI units whose values in SI units must be obtained experimentally," nor even in the table of "Other non-SI units." The year can be found, however, through the list of "Other non-SI units not recommended for use." This heading directs the reader to a National Institute of Standards and Technology (NIST) list where three kinds of year (365 days, sidereal, and tropical) are given with conversion to seconds, but are set in type to indicate "in general not to be used in NIST publications." Table 1 summarizes some of the uses of the year in other publications. For example, in the IUPAC chemistry document,[3] the year is not a constant; in the International Astronomy Union Style Guide,[5] the year (Julian) is a constant.

The phrase "the year as a derived unit of time" in the title of reference 1 is inconsistent with the SI, where the words "derived unit" have precise meaning. The year cannot be an SI derived unit because it is not a product of powers of base units.

As reference 1 noted, geochronologists who deal with decay constants (and half-lives) of long-lived radioactive nuclides would find a unit of measurement longer than the SI second to be advantageous. Ideally, this unit would be defined, with a high degree of precision, in terms of the SI second. It is unclear from their recommendations whether they would call this unit a year or an annus or both. The same symbol should not be used for both year and annus, as considerable confusion would result. The authors make clear that the year is not a constant[1] ("variations of the year over time"). The annus, as they define it, is a constant.

TABLE 1. THE USE OF YEAR OR THE SYMBOL A IN SELECTED REFERENCES*

Reference	Scientific field	Year listed on table of non-SI conversions	"a" as symbol for§	ka, Ma, Ga used	Conversion (Ms)
IUPAC Green Book [3]	Chemistry	yes	year	no	≈31.1557
IUPAP Red Book [6]	Physics	as footnote only	year (année)	no	.
IAU Style [4]	Astronomy	yes	year (Julian)	no	31.15576
NIST Guide [7]	Standards	yes	†	no	.
BIPM (SI) [2]	Measurement	indirectly	atto- (10-18)	no	.
International Stratigraphic Guide [8]	Geological Sciences	no	years before present (with k, G, M only)	yes	.

*The first four references are cited by [1] in support of the use of year or annus (symbol, a) as accepted for use with the SI. The word "annus" is not in any of them.
§The use of the single letter "a" as a symbol or shorthand notation for a specified number of seconds is undesirable for several reasons. Aside from the obvious lack of euphony of "annus," the single letter "a-" is an official SI prefix (10^{-18}) and has been used in astronomy with different meaning. The symbol for petaannuses would be Pa (international symbol for the unit of pressure Pascal). The single letter "a" is a word in several languages. In English, it is awkward to say or write "1 to 2 a ago." Consider the French "il y a 1 à 2 a" and the Spanish "hace 1 a 2 a."
†Although Ref [7] stated that there is no universally accepted symbol for the year, they cited a reference that suggests the symbol a.

Where reference 1 noted "that use of units for time in the geological literature is inconsistent," I would restate this passage to say "expression of time concepts in the geologic literature is inconsistent"—then add my emphatic agreement. One international standard that was not mentioned by the authors is ISO 8601.[5] Although this document deals with digital coding of dates and times, its *section 2.1, Basic concepts*, clarifies and clearly distinguishes among the concepts of time point, time interval, and duration. A search of the geological literature makes it clear that these concepts are expressed differently by different specialists, and that the various specialist groups need to share their thoughts, methods, and communication tools with other groups before anything resembling a consensus can be reached. As an example, the expression "1 ka" can mean, in addition to the 31.155 692 5445 Gs proposed by Ref [1]: 31.15576 Gs, 1000 years, 1000 years ago, 1000 years before 1950 (950 CE), 1000 years before I write this (1011 CE).

How do we proceed? The proposal by Holden et al.[1] should be not be accepted in its present form. It can and should serve as impetus for interdisciplinary conversation.

References

1. (a) N. E. Holden, M. L. Bonardi, P. De Bièvre, P. R. Renne, I. M. Villa, *Pure Appl. Chem.* 83, pp. 1159-1162 (2011); (b) ibid. Episodes 34, pp. 39-40(2011).
2. BIPM. *Le Système international d'unités – The International System of Units SI. 8th ed.* Bureau International des Poids et Mesures, Geneva (2006). www.bipm.org/utils/common/pdf/si_brochure_8.pdf
3. IUPAC. Quantities, Units and Symbols in Physical Chemistry, 3rd ed. (the "Green Book"). Prepared for publication by E. R. Cohen, et al., p. 137, RSC Publishing, Cambridge, UK (2007).
4. Recommendations concerning units. Reprinted from the "IAU Style Manual" by G. A. Wilkinson, Comm. 5, in IAU Transactions XXB (1987). www.iau.org/science/publications
5. *ISO. International Standard ISO 8601,* 3rd ed. Data elements and interchange formats — Information interchange — Representation of dates and times, Geneva (2004). www.phys.uu.nl/~vgent/calendar/downloads/iso_8601_2004.pdf
6. IUPAP. Symbols, Units and Nomenclature and Fundamental Constants in Physics
7. A. Thompson and B. N. Taylor. Special Publication 811: Guide for the Use of the International System of Units (SI), National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA (2008). http://physics.nist.gov/cuu/pdf/sp811.pdf
8. A. Salvador. *International Stratigraphic Guide: A guide to stratigraphic classification, terminology and procedure, 2nd ed.* Trondheim, Norway, and Boulder, Colorado, (1994).

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Time Conventions and Symbols for use in Nuclear Chemistry and the Earth and Planetary Sciences

by Nicholas Christie-Blick

A short article published recently in *Pure and Applied Chemistry*[1] sets out to rationalize the definition and symbols for units of time for use in nuclear chemistry and the Earth and planetary sciences. Given that the authors are members of a task group established jointly by the International Union of Pure and Applied Chemistry (IUPAC) and the International Union of Geological Sciences (IUGS), and that publication was approved by both bodies, one might reasonably assume that the recommendations reflect a workable consensus. Regrettably, they don't.[2]

At stake is whether or not a necessary distinction exists between geohistorical dates and spans of geological time. The task group argues that they are one and the same; the symbols 'a' (for 'annus', or year) and ka, Ma and Ga (for 10^3, 10^6 and 10^9 years, respectively) will suffice for both purposes. However, the distinction has proven vital for communication among Earth scientists for more than thirty years. And according to that well established convention, the symbols ka, Ma and Ga refer explicitly to points in time. Intervals of time require a different abbreviation or symbol: for example, m.y. or Myr in the case of millions of years.

The critical issue is not whether a single set of symbols will work, or whether language will become unnecessarily cumbersome to avoid confusion (though in my view it will). It is whether the adoption of two sets of *symbols*, not *units*, is in fact "inconsistent both internally and with respect to SI" because that is the justification being offered in support of a change. This assertion cannot be sustained. No-one objects to the storming of the Bastille on 14 July 1789 or to the construction of Stonehenge from 2600–1600 BC. And with reference to the latter, we say that the job took 1000 years, not 1000 BC. The distinction between geohistorical dates and spans of geological time is conceptually analogous. There is no internal inconsistency and SI rules don't apply to dates in either case because points in time are not units, even if they are specified in years. The year, moreover, is a non-SI unit. It cannot be a "derived unit of time," the designation proposed by the task group, because under SI conventions derived units are products of powers of base units (seconds in this case). The task group is thus intent on fixing a problem that doesn't exist, and in a manner that is at odds with their stated goal of "adherence to SI rules."

A possible compromise exists. That is to reserve the symbols a, ka, Ma and Ga for geohistorical dates in 10^0 10^3, 10^6 and 10^9 years before present (consistent with present usage), and to express geohistorical time in yr, kyr, Myr and Gyr (again adopting SI prefixes). The latter could then be used in the manner that the task group recommends, with no conflict, and with the outcome eventually to be determined by usage rather than by fiat. IUPAC would be well advised to place a moratorium on its new convention until a true consensus of those affected can be established.

References

1. N. E. Holden, M. L. Bonardi, P. De Bièvre, P. R. Renne, I. M. Villa, *Pure Appl. Chem.* 83, pp. 1159-1162 (2011).
2. N. Christie-Blick. Geological time conventions and symbols, *GSA Today*, submitted June 10, 2011.

Letter submitted 11 June 2011.

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Invited Response by the IUPAC/IUGS Task Group

by N.E. Holden,[1,3] M.L. Bonardi,[1,4] P. De Bièvre,[1,5] P.R. Renne, [2,6,7] and I.M. Villa[2,8,9,‡]

Stratigraphy is a sub-field within the International Union of Geological Sciences (IUGS). After almost two years of discussion on the convention by IUPAC and IUGS on the definition of the year, the Executive Committee of the IUGS agreed to approve it. The present exchange appears to be due to some members of the sub-field stratigraphy being unhappy with the decision that was made by the leaders of the IUGS.

In his letter, Christie-Blick re-iterates objections abundantly known to the scientific community and weighed on their merits during the extensive peer-review process that led to the final formulation of our paper. He argues that a distinction exists between geo-historical dates and unconstrained spans of geological time that requires two distinct symbols for the quantity of time, year, but not for the second. Indeed, the second also denotes both a time interval = duration, and an absolute point in time (which puts the ISO 8601 guideline in the completely opposite perspective to that perceived by Edwards in her letter).

In some sub-fields of science, there occur situations where a specialized name and a symbol for a quantity might be used for convenience, such as the use of the name, barn, and the symbol, b, for the unit of area in nuclear reactions. This occurs because the SI unit, metre^2, with symbol, m^2, requires a very large factor of 10^{-28} and this becomes inconvenient to use. However, Christie-Blick proposes two separate symbols, (a) and (yr), for the same unit, year.

It should be pointed out that the Systeme International d'Unites (SI) units are used both to denote an interval (the meter, the second, the kelvin, the ampere) and an absolute point. A current of 2 A (absolute point) is 0.1 A stronger (relative amount) than a current of 1.9 A (absolute point) and heats up a resistor by 0.2 K (relative amount) from an initial temperature of 298 K (absolute point). If Christe-Blick's point were generalized, the use of the same symbol, K, for a relative amount and an absolute point would cause confusion: every scientist would think that a temperature of 0.2 K is below the boiling temperature of liquid helium, and would expect this resistor to become a super-conductor.

There is no need here for a moratorium. Scientific conventions do not have the power to enforce a ban. Firkins and feet are still used in parts of the world in lieu of m^3 and m. Units such as "knot" are even used in different meanings by carpet sellers and by seamen. What a scientific convention can do is point to what is considered correct as a result of very long and very careful evaluations of all possible arguments that are available at a given time after weighing of their merits.

In her letter, Edwards lists a number of objections to the published reommendations on the use and the definition of the year as a practical unit for dealing with very long time periods in nuclear chemistry and in earth and planetary sciences. As we have stated in the paper, the unit of time in the SI, second, is not practical in the case of the half-lives or their reciprocal, decay constants, of long-lived radio-isotopes that are published in the fields of nuclear physics, of nuclear chemistry and of geochronology.

The annus (symbol: a) was brought into Earth Sciences by the International Commission of Stratigraphy (more precisely, by the Subcommission on Geochronology) in the early 80s, presumably to try and harmonize a diversity of units (published variations to express 10^9 years up to then were AE (aeons), G.y., Byr, b.yrs). All time units up to that point respected the requirement to follow the distributive law of mathematics, whereby 3 Byr – 2 Byr = 1 Byr (also note that the distributive law is a "standard use", it is not an "international standard reference material").

In Edward's summary Table, the past editions of the Green Book (IUPAC) and the Red Book (IUPAP) are quoted as not conforming to our definition. Indeed, the point of our paper was adding something which wasn't there! Remember that e.g. the kelvin also didn't exist when BIPM first defined metre and kilogram. Actually, both Green Book and Red Book are expand-

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ing their listing of time units to include the a (and ka, Ma, Ga), taking into full account the new recommendations. The correct citation in the Table should therefore have been the updated 2012 Green Book and Red Book. Finally, the mention of the *prefix* a (for atto, 10^{-18}) could appear misleading, but the homophony of the *unit* m with the *prefix* m has not, so far, proved a weighty argument for the abandonment of the metre. No scientist could confuse am (atto-metre) with "morning hours before noon" or with "annus-milli" or with a conjugated form of the English verb "to be" – context being the key of intelligent reading.

A difficulty that we encountered in the definition of the annus is the fact that the year is not commensurable with the day and several possible definitions of the year such as Julian, Mayan, Gregorian, Tropical (or Solar) and Sidereal all disagree; moreover, the Earth's orbital movement is variable. Most often authors report their half-life results in years but fail to define this term. We offered the solution, which was accepted after long evaluation by the IUPAC and the IUGS, by using a definition of the annus in terms of the SI unit, the second. Prior to the 1967 introduction of the atomic standard to define the second, the second had been defined in terms of a fraction of the tropical year, for the epoch 1900.0 as "the second is the fraction 1/31 556 925.9747 of the tropical year for 1900 January 1 at 12 hours ephemeris time".

Since the tropical year is not constant (with which Edwards agrees), we needed to define a unit for time in such a way that it can be considered as a constant for practical purposes. We recommended annus be defined directly in terms of the SI unit, the second. We reversed the old definition and took into account the non-relativistic estimate of the astronomical decrease by 0.530 s per century for the epoch 2000.0, and obtained the annus as 1 a = 31 556 925.445 s.

We noted that a can be supplemented with prefixes k ($\times 10^3$), M ($\times 10^6$) and G ($\times 10^9$), i.e., ka, Ma and Ga to designate thousand, million, and billion (USA usage) years, respectively. Half-lives can be expressed in ka, Ma or Ga, while decay constants and rates of geological processes in ka^{-1}, Ma^{-1}, or Ga^{-1}. In order to express an age, or absolute time, the same unit and symbol must be used as for time duration (as we mentioned earlier in this note), with the optional addition of qualifiers such as "ago" or "before present" if a disambiguation is required.

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