SI NOTICE (B4)

The International System of Units and its Use Within This Work

“The International System of Units, the SI, has been used around the world as the preferred system of units, the basic language for science, technology, industry and trade since it was established in 1960 by a resolution at the 11th meeting of the Conférence Générale des Poids et Mesures, the CGPM (known in English as the General Conference on Weights and Measures). […]

“The SI has always been a practical and dynamic system that has evolved to exploit the latest scientific and technological developments. In particular, the tremendous advances in atomic physics and quantum metrology made over the last 50 years have enabled the definitions of the second, the metre, and the practical representation of the electrical units to take advantage of atomic and quantum phenomena to achieve levels of accuracy for realizing the respective units limited only by our technical capability and not by the definitions themselves. […]

“The SI is a consistent system of units for use in all aspects of life, including international trade, manufacturing, security, health and safety, protection of the environment, and in the basic science that underpins all of these. The system of quantities underlying the SI and the equations relating them are based on the present description of nature and are familiar to all scientists, technologists and engineers.

“The definition of the SI units is established in terms of a set of seven defining constants. The complete system of units can be derived from the fixed values of these defining constants, expressed in the units of the SI. These seven defining constants are the most fundamental feature of the definition of the entire system of units. These particular constants were chosen after having been identified as being the best choice, taking into account the previous definition of the SI, which was based on seven base units, and progress in science. […]

“To be of any practical use, these units not only have to be defined, but they also have to be realized physically for dissemination. In the case of an artefact, the definition and the realization are equivalent – a path that was pursued by advanced ancient civilizations. Although this is simple and clear, artefacts involve the risk of loss, damage or change. The other types of unit definitions are increasingly abstract or idealized. Here, the realizations are separated conceptually from the definitions so that the units can, as a matter of principle, be realized independently at any place and at any time. In addition, new and superior realizations may be introduced as science and technologies develop, without the need to redefine the unit. These advantages – most obviously seen with the history of the definition of the metre from artefacts through an atomic reference transition to the fixed numerical value of the speed of light – led to the decision to define all units by using defining constants. […]

“The definitions of the SI units, as decided by the CGPM, represent the highest reference level for measurement traceability to the SI.

“Metrology institutes around the world establish the practical realizations of the definitions in order to allow for traceability of measurements to the SI. The Consultative Committees provide the framework for establishing the equivalence of the realizations in order to harmonize traceability world-wide.

“Standardization bodies may specify further details for quantities and units and rules for their application, where these are needed by interested parties. Whenever SI units are involved, these standards must refer to the definitions by the CGPM. Many such specifications are listed for example in the standards developed by the International Organization for Standardization and the International Electrotechnical Commission (ISO/IEC 80000 series of international standards).

"Individual countries have established rules concerning the use of units by national legislation, either for general use or for specific areas such as commerce, health, public safety and education. In almost all countries, this legislation is based on the SI. The International Organization of Legal Metrology (OIML) is charged with the international harmonization of the technical specifications of this legislation."[i]

It is from the above extract that the decision was drawn to use the SI as this works primary unitary system and, as such, all units are traceable back to this basic system. The Bureau International des Poids et Mesures, the BIPM (known in English as the International Bureau of Weights and Measures) is the direct source of all unitary definitions made within this work and should be considered the sole reference for metrology within this work.

"The value of a quantity is generally expressed as the product of a number and a unit. The unit is simply a particular example of the quantity concerned which is used as a reference, and the number is the ratio of the value of the quantity to the unit.

"For a particular quantity different units may be used. For example, the value of the speed v of a particle may be expressed as $v = 25\ \mathrm{m/s}$ or $v = 90\ \mathrm{km/h}$, where metre per second and kilometre per hour are alternative units for the same value of the quantity speed.

"Before stating the result of a measurement, it is essential that the quantity being presented is adequately described. This may be simple, as in the case of the length of a particular steel rod, but can become more complex when higher accuracy is required and where additional parameters, such as temperature, need to be specified.

"When a measurement result of a quantity is reported, the *estimated value* of the measurand (the quantity to be measured), and the *uncertainty* associated with that value, are necessary. Both are expressed in the same unit."[i]

When units, symbols and uncertainty are used in this work, it is in accordance with the latest guidance from the BIPM, which is published in *The International System of Units (SI) 9th Edition* (2019)[i], *Evaluation of Measurement Data — Guide to the Expression of Uncertainty in Measurement (JCGM 100:2008)* (2008)[ii], and *International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM) 3rd Edition (JCGM 200:2012)* (2012)[iii]. Additional guidance for uncertainty can be found in *The NIST Reference on Constants, Units, and Uncertainty*[iv]. The SI is defined within this work by this notice and the *D6 – SI Unit Definitions* and *D7 – SI Defining Physical Constants* datsheets. Additional companion sheets are also provided to aid the use of this unitary system.

The Extension to The International System of Units

This work utilises and recognises many other units that have not been accepted for use with the SI by BIPM and this notice also acts to extend the SI within this work. The unitary extension includes the following units: year (a), electronvolt mass ($\mathrm{eV/c^2}$), unified atomic mass unit (u or Da), and atmospheric pressure (atm). These units are defined by the International Astronomical Union (IAU), the International Science Council's Committee on Data (CODATA), the International Civil Aviation Organization (ICAO), and the International Organization for Standardization (ISO). The units within the extension are described and defined below:

Unit	Unit Symbol	Definition	Description	Defining Body
Year (Annum)	a	$1\ \mathrm{a} \equiv 365.25\ \mathrm{d}$ $1\ \mathrm{a} \equiv 31\,557\,600\ \mathrm{s}$	Julian Astronomical Year	IAU[v]
Electronvolt (mass)	$\mathrm{eV/c^2}$	$1\ \mathrm{eV/c^2} \equiv 1.782\,661\,92 \times 10^{-36}\ \mathrm{kg}$	Electronvolt Mass-Equivalence	CODATA[vi]
Unified Atomic Mass Unit (Dalton)	u or Da	$1\ \mathrm{u} \equiv 1.660\,539\,066\,60(50) \times 10^{-27}\ \mathrm{kg}$	Mass Relative to an Unbound Neutral Carbon 12 Atom	CODATA[vi]
Atmospheric Pressure (Standard Atmosphere)	atm	$1\ \mathrm{atm} \equiv 101\,325\ \mathrm{Pa}$	Relative Atmosphere of the Earth at Sea Level	ICAO and ISO[vii][viii]

The units above are used within this work as an extension to the SI and have been standardised to match the units, symbols and uncertainty guidance outlined by BIPM. The SI unit prefix system is utilised with this unitary system extension due to the standardisation process. Additional companion sheets are also provided to aid the use of this unitary system extension.

The SI Unit Prefix System

The SI unit prefix system defined by BIPM allows for numerical data length shortening in a similar way to standard form or scientific notation. By adding a prefix to an SI unit, the magnitude of data can altered by powers of 10^3 (one thousand) from 10^{30} (quetta) to 10^{-30} (quecto). Unit prefixes are commonly used within this work and form an essential tool for the unitary system. The full prefix system can be found within the companion sheet selection.

Time Unitary Conventions

Due to the SI extension described above, five units of time are analogous within this work. For this reason a convention has been implemented to enable consistency and transparency. Where a time period shorter than 1 minute (min) acts as numerical data, the second (s) is preferred for all uses with appropriate SI prefixes. For data between 60 seconds and 1 hour (h), the minute should be used exclusive of SI prefixes and, similarly, data between 60 minutes and 1 day (d) will be listed using the hour also excluding SI prefixes. For a period of 24 hours to 1 year (a), the day is preferred and must not be used with SI prefixes and for periods extending beyond 365.25 days, the year will be used alongside appropriate SI prefixes.

The second may be used as the SI base unit or the year as the largest unit of time to standardise numerical data within table columns and rows or graphs to prevent the use of time units within each table cell or graphical point when the unit is explicitly stated with graphical axes titles or table header rows or columns.

A companion sheet has been provided to aid conversions between time units and in cases where maximum accuracy is required, the second must always be used due to its status as the SI base unit for time.

Typesetting

Within this work, formulae, equations, numerical data provided with units, and related constant and quantity symbols are indicated using the Cambria Math typeface (for example, the speed of light, c, is defined as $299\,792\,458\ \mathrm{m/s}$). Numerical values exclusive of units will inherit the document typeface. Symbols for constants and quantities will be placed into an oblique typeset whilst units are the only letters to be placed into a roman typeface. Note that superscript, subscript and greek letters, characters and symbols are always placed into a roman typeface.

When numerical data is presented, groups of three digits are separated by white space delimiters in both the integer and fractional elements of numbers. For example, the number 1875402548.55834 is written as 1 875 402 548.558 34 to allow for subitizing. This is official policy accepted for use by many institutions including BIPM[ix].

Companion Sheets

Companion sheets for either the SI or the SI extension within this work can be found under section C. Some companion sheets have been provided for non-SI units that have not been outlined and defined in this statement to enable the international use of this work.

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[i] BIPM. (2019). Le Système International d'Unités / The International System of Units (9th ed). Bureau international des poids et mesures. `http://www.bipm.org/en/si/si_brochure`

[ii] BIPM. (2008). JCGM 100:2008 Evaluation of Measurement Data—Guide to the Expression of Uncertainty in Measurement. Bureau International des Poids et Mesures. `https://www.iso.org/sites/JCGM/GUM/JCGM100/C045315e-html/C045315e.html?csnumber=50461`

[iii] BIPM. (2012). JCGM 200:2012 International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM) (3rd ed). Bureau International des Poids et Mesures. `https://www.bipm.org/documents/20126/2071204/JCGM_200_2012.pdf/f0e1ad45-d337-bbeb-53a6-15fe649d0ff1`

[iv] NIST. (2017). Uncertainty of Measurement Results from NIST. `https://physics.nist.gov/cuu/Uncertainty/index.html`

[v] Wilkins, G. A. & International Astronomical Union. (1989). The IAU Style Manual: The Preparation of Astronomical Papers and Reports. `https://www.iau.org/static/publications/stylemanual1989.pdf`

[vi] CODATA & NIST. (2018). 2018 CODATA Recommended Values. The NIST Reference on Constants, Units, and Uncertainty. `https://physics.nist.gov/cuu/Constants`

[vii] ISO. (1975). ISO 2533:1975, Standard Atmosphere. International Organization for Standardization. `https://www.iso.org/obp/ui/#iso:std:iso:2533:ed-1:v1:en`

[viii] [PUBLIC] U.S. Standard Atmosphere, 1976 (NOAA-S/T-76-1562). (1976). `https://ntrs.nasa.gov/citations/19770009539`

[ix] Wallard, A. & BIPM. (2004). Resolution 10 of the 22nd CGPM: Symbol for the Decimal Marker. Metrologia, 41(1), 99–108. `https://doi.org/10.1088/0026-1394/41/1/M01`