National Metrology Centre
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Revision of the International System of Units (SI)

Impact and Guidelines for Implementation

REVISION OF THE SI

The International System of Units, the SI, with based units - the second, the metre, the kilogram, the ampere, the kelvin, the mole and the candela, is being revised. *For the first time, all of the base units of measurement will be defined by fundamental constants of nature, rather than by physical objects.*

The revision comes into force on 20 May 2019 was approved by the General Conference on Weights and Measures (CGPM), the international body responsible for the global comparability of measurements under the Metre Convention that provides the basis for a coherent measurement system worldwide that underpins scientific discovery and innovation, industrial manufacturing and international trade, as well as the quality of life and global environment.

As a signatory to the Metre Convention, Singapore is adopting the redefined SI to ensure that we are consistent with international best practice. The National Metrology Cerntre, A*STAR is the primary agency responsible for implementing the new SI definitions in Singapore.

SIGNIFICANCE

The revised SI definition is based on seven inherently stable physical constants expressed in explicit numerical values as shown in Appendix 1. The quantities have been chosen so that the revised definitions will not need to be modified to accommodate future improvements in the technologies used to realize them.

Making this revision to the SI is a profound change in the approach to measurements in science, industry and society. More widely, the revision ensures that the SI remains robust for the future, and is ready to embrace the advancements in science, technology and innovation.

The revised SI definition also takes into consideration that, while the change offers increased precision to meet the ever increasing demand for making precise and accurate measurements, the change is also a smooth transition so that most users will not notice the difference in everyday life.

WHAT IS THE IMPACT?

The kilogram is defined in terms of the Plank constant instead of international prototype of the kilogram (IPK) to ensure long-term stability of the SI mass scale. The kilogram can be realized by any suitable method, such as using the Kibble (watt) balance or the Avogadro (X-ray crystal density) method. The value of the Planck constant is chosen to ensure that there is no change in the SI kilogram value but with a small uncertainty of 10 µg (k = 1) assigned to the IPK that broadly not affecting the general users.

The kelvin is redefined with no immediate effect on temperature measurement practice or on the traceability of temperature measurements, and will not affecting most users. The practical realization of the kelvin supports the dissemination of thermodynamic temperature measurement that is equally through the defined scales ITS-90.

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The mole is redefined with respect to a specified number of atoms or molecules, and will no longer depend on the unit of mass, the kilogram. Traceability to the mole can still be established via all previously employed approaches including, but not limited to, the use of mass measurements along with tables of atomic weights and the molar mass constant, with very small measurement uncertainty that not require any change in common practice.

The revised definition of the SI has no impact on the second, the metre and the candela.

The ampere and other electrical units are practically realized primarily by fixed values of the Planck constant *h*, and the elementary charge *e*. The new values of *h* and *e* are slightly different from those used to set the 1990 conventional values in deriving Josephson Constant K_{J-90} and von Klitzing Constant R_{K-90}, which are used for practical realization of the units of voltage and resistance respectively. To become fully coherent with the revised SI, small discontinuous change of the related quantities is to implemented on 20 May 2019[1].

Quantum primary standards such as Josephson voltage standards and quantum Hall resistance standards are having their reference values updated with relative correction change, ***d***, about $+1.067\times10^{-7}$ for voltage related quantities and about $+1.779\times10^{-8}$ for resistance related quantities. Typical small correction for some of the electrical quantities as a result of the SI revision are shown in the following table:

Electrical Quantity	**Relative Correction *d***
Voltage	$+0.1067 \times 10^{-6}$
Resistance	$+0.0178 \times 10^{-6}$
Current	$+0.0889 \times 10^{-6}$
Power	$+0.1956 \times 10^{-6}$
Capacitance	-0.0178×10^{-6}
Inductance	$+0.0178 \times 10^{-6}$

General criteria[2] that can be used to decide what action should be taken on the implementation day for the electrical quantities are shown below. In general, if the existing $k = 2$ expanded relative uncertainty, ***U***, of any particular artifact or measurement is such that:

Criteria	**Action required**
Relative expanded uncertainty ***U*** is 2.5 times or larger than the relative change ***d*** **U ≥ 2.5 *d***	*No action is necessary until the next calibration or measurement*. The previous calibration data is still metrologically valid and any use of this data between implementation day and the next calibration date should have an insignificant impact.
Relative expanded uncertainty ***U*** is less than 2.5 times of the relative change ***d*** ***U* < 2.5 *d***	*Numerical correct or recalibrate before the next use of the instruments*.

Calibrations and measurements of electrical quantities performed at NMC from 20 May 2019 onward are fully coherent with the revised SI and no further adjustment by the users is needed.

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[1] K_{J-90}=483 597.9 GHz/V and R_{K-90}=25 812.807 Ω. In the revised SI, $K_J=2e/h$=483 597.848 416 984 GHz/V and $R_K=h/e^2$=25 812.807 459 3045 Ω

[2] Consultative Committee for Electricity and Magnetism (CCEM) "*CCEM Guidelines for Implementation of the 'Revised SI'*, Version 1.

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All National Metrology Institutes in the world will implement the same changes on 20 May 2019, so the international compatibility of SI traceable measurements warranted by the CIPM Mutual Recognition Arrangement will be unaffected.

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Appendix 1: 2019 Revision to the International System of Units (SI)

Effective from 20 May 2019, the international System of Units is the system of units in which:

- Unperturbed ground state hyperfine transition frequency of the caesium 133 atom $\Delta\nu_{Cs}$ is 9192631770 Hz,
- Speed of light in vacuum *c* is 299792458 m/s,
- Planck constant *h* is $6.62607015 \times 10^{-34}$ J s,
- Elementary charge e is $1.602\,176\,634 \times 10^{-19}$ C,
- Boltzmann constant *k* is 1.380649×10^{-23} J/K,
- Avogadro constant N_A is $6.02214076 \times 10^{23}$ mol^{-1},
- Luminous efficacy of monochromatic radiation of frequency 540×10^{12} Hz, K_{cd} is 683 lm/W.

Quantity	Base units of the SI
time	The ***second***, symbol s, is the SI unit of time. It is defined by taking the fixed numerical value of the caesium frequency $\Delta\nu_{Cs}$, 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}.
length	The ***metre***, symbol m, is the SI unit of length. It is defined by taking the fixed numerical value of the speed of light in vacuum c to be 299 792 458 when expressed in the unit m s^{-1}, where the second is defined in terms of $\Delta\nu_{Cs}$.
mass	The ***kilogram***, symbol kg, is the SI unit of mass. It is defined by taking the fixed numerical value of the Planck constant h to be $6.626\,070\,15 \times 10^{-34}$ when expressed in the unit J s, which is equal to kg m^2 s^{-1}, where the metre and the second are defined in terms of c and $\Delta\nu_{Cs}$.
electric current	The ***ampere***, symbol A, is the SI unit of electric current. It is defined by taking the fixed numerical value of the elementary charge *e* to be $1.602\,176\,634 \times 10^{-19}$ when expressed in the unit C, which is equal to A s, where the second is defined in terms of $\Delta\nu_{Cs}$.
thermodynamic temperature	The ***kelvin***, symbol K, is the SI unit of thermodynamic temperature. It is defined by taking the fixed numerical value of the Boltzmann constant *k* to be $1.380\,649 \times 10^{-23}$ when expressed in the unit J K^{-1}, which is equal to kg m^2 s^{-2} K^{-1}, where the kilogram, metre and second are defined in terms of *h*, *c* and $\Delta\nu_{Cs}$.
Amount of substance	The ***mole***, symbol mol, is the SI unit of amount of substance. One mole contains exactly $6.022\,140\,76 \times 10^{23}$ elementary entities. This number is the fixed numerical value of the Avogadro constant, NA, when expressed in the unit mol^{-1} and is called the Avogadro number. The amount of substance, symbol *n*, of a system is a measure of the number of specified elementary entities. An elementary entity may be an atom, a molecule, an ion, an electron, any other particle or specified group of particles.
luminous intensity	The ***candela***, symbol cd, is the SI unit of luminous intensity in a given direction. It is defined by taking the fixed numerical value of the luminous efficacy of monochromatic radiation of frequency 540×10^{12} Hz, K_{cd}, to be 683 when expressed in the unit lm W^{-1}, which is equal to cd sr W^{-1}, or cd sr kg^{-1} m^{-2} s^3, where the kilogram, metre and second are defined in terms of *h*, *c* and $\Delta\nu_{Cs}$.

Reference: 26th Meeting of the General Conference on Weights and Measures (CGPM), Resolution 1: On the revision of the International System of Units (SI)