NEW SI BASE UNITS

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1 Introduction

The current International System of Units (SI) has emerged by his perhaps most significant revision until now. This revision was voted at the 26th General Conference on Weights and Measures (CGPM) in November 2018. The revision changed the definitions of SI base units, which are now fundamentally different from those previously used. Now, the seven SI base units are defined using only seven "defining constants" whose values are taken as perfectly exact. The definitions are published in the 9th edition of "SI Brochure" and are applied from 20th May 2019.

As it was the case in the past revisions of the SI, measurements based on previous definitions of the units remain valid within their measurement uncertainties. Thanks to that, the revision did not produce a noticeable impact on daily life.

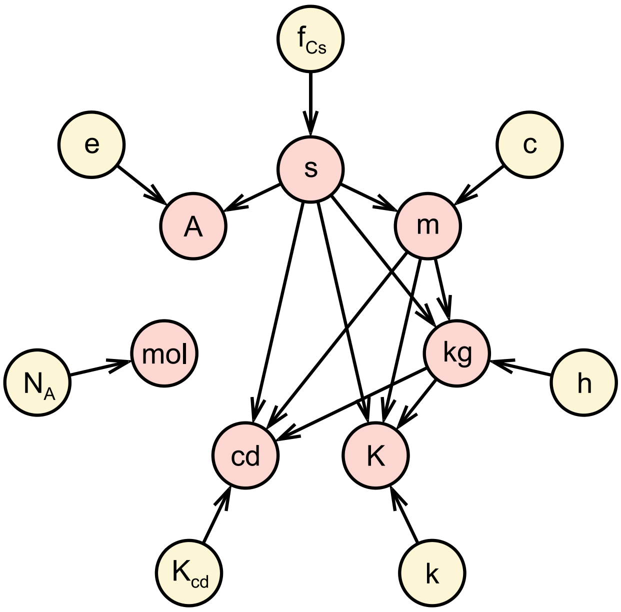

Figure 2.1. The SI base units are defined using the set of only seven defining constants (given in the external circles) whose values are taken as exact. Each base unit is defined, either, through the corresponding constant from the set, or through the constant from the set and other base units that are also defined through the constants from that set. See Table 2.1.

Table 2.1 The definitions of the SI base units [SI] 2.2, 2.3.1

Defining constant	
Symbol	Definition
f_{Cs}	The unperturbed ground state hyperfine transition frequency of the caesium 133 atom is exactly 9 192 631 770 Hz.
c	The speed of light in vacuum is exactly 299 792 458 m / s.
h	The Planck constant is exactly $6.626\,070\,15 \cdot 10^{-34}$ J · s.
e	The elementary charge is exactly $1.602\,176\,634 \cdot 10^{-19}$ C.
k	The Boltzmann constant is exactly $1.380\,649 \cdot 10^{-23}$ J / K.
N_A	The Avogadro constant is exactly $6.022\,140\,76 \cdot 10^{23}$ of specified elementary entities per mole.
K_{cd}	The luminous efficacy of monochromatic light of frequency $540 \cdot 10^{12}$ Hz is exactly 683 lm / W.

Definition of the SI base unit			
Name of SI base quantity	SI base unit		
	Name	Symbol	Definition
time	second	s	$1\,\mathrm{s} = \dfrac{9\,192\,631\,770}{f_{Cs}}$
length	metre	m	$1\,\mathrm{m} = \dfrac{c}{299\,792\,458}\,\mathrm{s}$
mass	kilogram	kg	$1\,\mathrm{kg} = \dfrac{h}{6.626\,070\,15 \cdot 10^{-34}}\,\dfrac{\mathrm{s}}{\mathrm{m}^2}$
electric current	ampere	A	$1\,\mathrm{A} = \dfrac{e}{1.602\,176\,634 \cdot 10^{-19}}\,\dfrac{1}{\mathrm{s}}$
thermodynamic temperature	kelvin	K	$1\,\mathrm{K} = \dfrac{1.380\,649 \cdot 10^{-23}}{k}\,\dfrac{\mathrm{kg} \cdot \mathrm{m}^2}{\mathrm{s}^2}$
amount of substance	mole	mol	$1\,\mathrm{mol} = \dfrac{6.022\,140\,76 \cdot 10^{23}}{N_A}$
luminous intensity	candela	cd	$1\,\mathrm{cd} = \dfrac{K_{cd}}{683}\,\dfrac{\mathrm{kg} \cdot \mathrm{m}^2}{\mathrm{s}^3 \cdot \mathrm{sr}}$

2 SI base units

Seven SI base units are defined using only the seven defining constants. Seven fundamental physical constants of high reproducibility were used as **defining constants**. The values of these constants were fixed after being identified as the best estimates at the time just before the decision on the revision of the SI. In this way, the SI is scaled to the seven physical constants, which consequently become perfectly exact. See Figure 2.1 and Table 2.1. The reference definitions of base units are published in the “SI Brochure”, see [SI].

The current definitions of SI base units have brought important benefits. The most important are:

1) a large number of physical constants become either exactly known or known with higher accuracy

2) values of quantities that are much smaller or much larger than the base units can be measured with unreduced accuracy

3) liberation of mass metrology from the unit based on the mass standard which is undoubtedly changing with time

4) the Josephson effect and Hall effect can be used to directly realize the SI definitions of most electrical units

5) the definition of the kelvin does not make reference to a water having the defined isotopic composition.

Some of the consequences of the current definitions are that the following constants are not exactly known, and must be measured:

1) the magnetic constant, the electric constant and the characteristic impedance of a vacuum

2) the temperature of triple point of water

3) the molar mass of carbon 12.

The following text provides an interpretation of the definitions of base units.

Second is the duration of 9 192 631 770 periods of the radiation produced by the transition between the two hyperfine levels of the caesium 133 atom if it would be free of any perturbation, at rest and in the absence of electric and magnetic fields.

Such a defined second is the unit of time compliant with the general theory of relativity. Significant relativistic and other effects, which the definition of the second excludes, must be estimated and correction applied to provide the proper value of the second at a point of realization, for example, at a connector of frequency standard. Significant effects arise from the Doppler effect due to the atomic motion, the thermal radiation of an environment, and other effects related to instruments design.

Metre is the length of a path travelled by light in vacuum during the time interval of $\frac{1}{299\,792\,458}$ of the second.

Kilogram is a mass that has the value equal to the Planck constant divided by $6.626\,070\,15 \cdot 10^{-34}\ \mathrm{m^2/s}$.

Ampere is a constant flow, through a specified surface, of $\frac{1}{1{,}602\,176\,634 \cdot 10^{-19}}$ elementary charges per second.

Kelvin is a change of thermodynamic temperature that produces a change of thermal energy $k \cdot T$ by $1.380\,649 \cdot 10^{-23}$ J. The scale of temperature expressed in kelvins, T, has zero value at the theoretically lowest (but unattainable) temperature at which the kinetic energy of a molecule is equal to zero.

Thermodynamic temperature (**temperature**) is the quantity proportional to an average kinetic energy of entities which are considered as wholes. The entities may be anything, for example: electrons, molecules, 1 kg weights.

The temperature expressed in kelvins, T, at the average kinetic energy $\bar{E}$ per the degrees of freedom of entities which are considered as wholes, is given by the formula $T = 2 \cdot \frac{\bar{E}}{k}$.

Mole is an amount of substance of $6.022\,140\,76 \cdot 10^{23}$ elementary entities.

When the mole is used, it is important to specify a substance and an elementary entity involved. The elementary entity may be an electron, ion, atom, molecule, and any other particle or group of particles.

Candela is the luminous intensity of a source that emits monochromatic light of frequency $540 \cdot 10^{12}$ (wavelength of 555 nm) in a given direction in which it has a radiant intensity of $\frac{1}{683}$ watt per steradian.

Steradian is the solid angle limited by an arbitrary conical surface, but which is such that surrounds an area of 1 m^2 on a sphere with the radius of 1 m and with the center at the top of the conical surface.

The base unit is possible to realize only by a standard in a local space where it is compared with other quantity in that space for a measurement purpose. Then the value of the realized unit is a proper value used to determine a measurement result.

The definitions of base units do not limit ways in which the units are realized. (For now, the exception is the definition of the second whose primary etalon, and not other etalons, must use the microwave radiation of the caesium 133 atom.) The unit might be realized in any way which provides sufficient accuracy and which gives a value of quantity traceable to the seven defining constants. The outlines of realization of the seven base and other important units are given in Appendix 2 of the “SI Brochure”. See [SI realization].

Anyone with the ability to make sufficiently accurate measurements through the defining constants is able to realize the base as well as derived units.

3 Terms

Accuracy of a value is a qualitative concept which indicates a closeness of this value to a reference value.

Average of values is the arithmetic mean of these values**.**

Best estimate is an estimate of value according to specific requirements on a basis of available data.

Constant is a value considered unchanging during certain consideration.

Definition of a concept is a determination of that concept.

Fundamental physical constant (**fundamental constant**) is a physical constant of high reproducibility.

General theory of relativity is the theory which completely describes gravitation, space and time.

Local space is a (small) space with the uniform gravitational field of any magnitude, at any place, at relative rest or in motion.

Measurement result (or **estimated value**) is a value assigned to a measurand on the basis of one or more results of measurements.

Measurement standard (**standard**, or **etalon**) is a device for measurement intended to realize, reproduce or define the value of a quantity to serve as a reference in measurements.

Metrological traceability (**traceability**) is the distinction of a measurement result which means that its specification of combined standard uncertainty includes uncertainties of all its component values beginning from a source of traceability.

Physical constant (or **universal constant**, or **empirical constant**) is the value of a quantity which is identical under the identical conditions.

Proper value is the value of a quantity which is realized in a local space where it is compared with other quantity which is in the same space for measurement purposes.

Reproducibility of measurement results (**reproducibility**) denotes closeness of the measurement results of the same measurand, carried out under changed measurement conditions.

Source of traceability is a quantity that is at the beginning of the traceability chain.

Traceability chain is an unbroken sequence of calibrations and traceable results of these calibrations.

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