# 2019 redefinition of the SI base units

Article Talk

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In 2019, four of the seven SI base units specified in the International System of Quantities were redefined in terms of natural physical constants, rather than human artifacts such as the standard kilogram.[1][2] Effective 20 May 2019, the 144th anniversary of the Metre Convention, the kilogram, ampere, kelvin, and mole are now defined by setting exact numerical values, when expressed in SI units, for the Planck constant ($h$), the elementary electric charge ($e$), the Boltzmann constant ($k_B$), and the Avogadro constant ($N_A$), respectively. The second, metre, and candela had previously been redefined using physical constants. The four new definitions aimed to improve the SI without changing the value of any units, ensuring continuity with existing measurements.[3][4] In November 2018, the 26th General Conference on Weights and Measures (CGPM) unanimously approved these changes,[5][6] which the International Committee for Weights and Measures (CIPM) had proposed earlier that year after determining that previously agreed conditions for the change had been met.[7]:23 These conditions were satisfied by a series of experiments that measured the constants to high accuracy relative to the old SI definitions, and were the culmination of decades of research.

The previous major change of the metric system occurred in 1960 when the International System of Units (SI) was formally published. At this time the metre was redefined: the definition was changed from the prototype of the metre to a certain number of wavelengths of a spectral line of a krypton-86 radiation, making it derivable from universal natural phenomena.[Note 1] The kilogram remained defined by a physical prototype, leaving it the only artifact upon which the SI unit definitions depend. At this time the SI, as a coherent system, was constructed around seven *base units*, powers of which were used to construct all other units. With the 2019 redefinition, the SI is constructed around seven defining *constants*, allowing all units to be constructed directly from these constants. The designation of base units is retained but is no longer essential to define the SI units.[4]

The metric system was originally conceived as a system of measurement that was derivable from unchanging phenomena,[8] but practical limitations necessitated the use of artifacts – the prototype of the metre and prototype of the kilogram – when the metric system was introduced in France in 1799. Although it was designed for long-term stability, the masses of the prototype kilogram and its secondary copies have shown small variations relative to each other over time; they are not thought to be adequate for the increasing accuracy demanded by science, prompting a search for a suitable replacement. The definitions of some units were defined by measurements that are difficult to precisely realise in a laboratory, such as the kelvin, which was defined in terms of the triple point of water. With the 2019 redefinition, the SI became wholly derivable from natural phenomena with most units being based on fundamental physical constants.

A number of authors have published criticisms of the revised definitions; their criticisms include the premise that the proposal failed to address the impact of breaking the link between the definition of the dalton[Note 2] and the definitions of the kilogram, the mole, and the Avogadro constant.

# Avogadro constant

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The **Avogadro constant**, commonly denoted $N_A$[1] or $L$,[2] is an SI defining constant with an exact value of 6.022 140 76 × $10^{23}$ $mol^{-1}$ (reciprocal moles).[3][4] It is defined as the number of constituent particles (usually molecules, atoms, or ions) per mole (SI unit) and used as a normalization factor in the *amount of substance* in a sample. In practice, its value is often approximated to 6.02×$10^{23}$ $mol^{-1}$ or 6.022×$10^{23}$ $mol^{-1}$.[5] The constant is named after the physicist and chemist Amedeo Avogadro (1776–1856).

**Avogadro constant**

Amedeo Avogadro, the constant's namesake

| | |
|---|---|
| **Common symbols** | $N_A$, $L$ |
| **SI unit** | $mol^{-1}$ |
| **Exact value** | |
| reciprocal mole | 6.022 140 76 × $10^{23}$ |

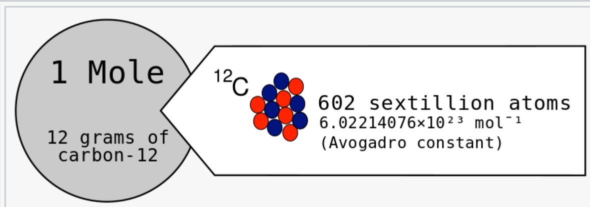
The Avogadro constant $N_A$ is also the factor that converts the average mass of one particle, in grams, to the molar mass of the substance, in grams per mole (g/mol).[6]

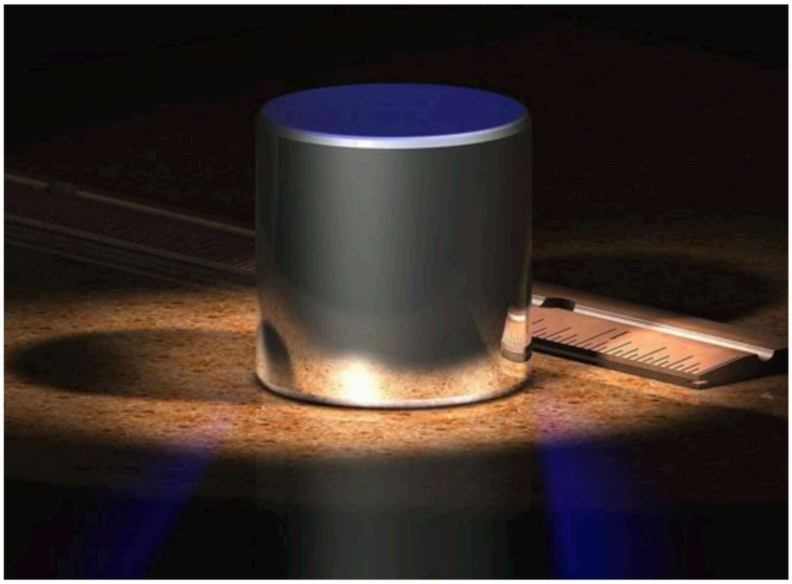
The constant $N_A$ also relates the molar volume (the volume per mole) of a substance to the average volume nominally occupied by one of its particles, when both are expressed in the same units of volume. For example, since the molar volume of water in ordinary conditions is about 18 mL/mol, the volume occupied by one molecule of water is about 18/(6.022 × $10^{23}$) mL, or about 0.030 $nm^3$ (cubic nanometres). For a crystalline substance, $N_0$ relates the volume of a crystal with one mole worth of repeating unit cells, to the volume of a single cell (both in the same units).

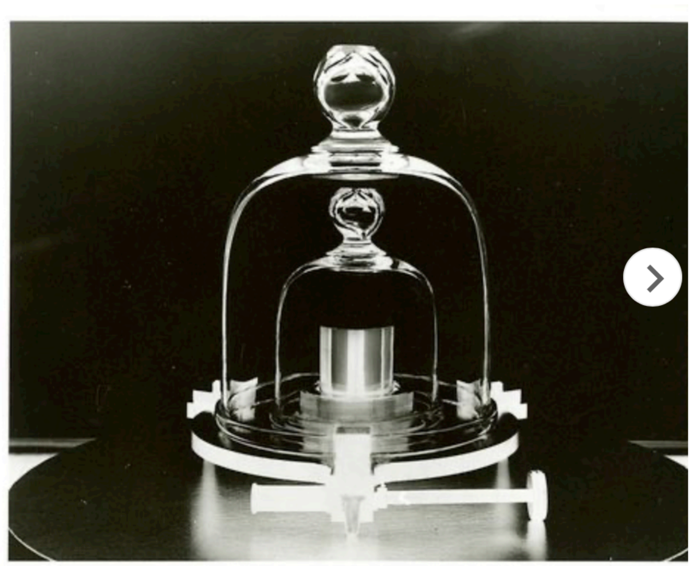
In the SI dimensional analysis of measurement units, the dimension of the Avogadro constant is the reciprocal of amount of substance, $N^{-1}$. The **Avogadro number**, sometimes denoted $N_0$,[7][8] is the numeric value of the Avogadro constant (i.e., without units), namely the dimensionless number 6.022 140 76 × $10^{23}$.[1][9]

## Definition [ edit ]

The Avogadro constant was historically derived from the old definition of the mole as the amount of substance in 12 grams of carbon-12 ($^{12}C$); or, equivalently, the number of daltons in a gram, where the dalton is defined as $\frac{1}{12}$ of the mass of a $^{12}C$ atom.[10] By this old definition, the numerical value of the Avogadro constant in $mol^{-1}$ (the Avogadro number) was a physical constant that had to be determined experimentally.







Computer-generated image of Le Grand K. GREG L/CC BY-SA 3.0

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**FROM 1889 TO 2019, THE** mass of a kilogram was defined by an object known as the international prototype kilogram (IPK) or, less formally, Le Grand K. A kilogram was a kilogram because of this object: a platinum alloy cylinder that sits in a vault on the outskirts of Paris.

Le Grand K is located in an environmentally monitored safe in a lower vault in the basement of the International Bureau of Weights and Measures in Sèvres, Paris. Housed under three bell jars, access to this precious cylinder requires three keys, operated independently, of which only two are kept in France.


Avenue du Pavillon de Breteuil
Saint-Cloud
France

The foundational unit of the system was the meter, which was supposed to be one ten-millionth the distance from the North Pole to the equator along the Paris meridian. (Scientists at the time made a slight error in their measurements, and the meter is about 2 millimeters longer than it should be.)

At the same time, the kilogram was defined as the mass of 1,000 cubic centimeters of water at 4 degrees Celsius.

These units were adopted by the French Republic in 1795, although in practice, people continued to use their own local measurements for decades.

"It's not like everyone jumped on the bandwagon as soon as the metric system was formalized," said Barry Taylor, a scientist emeritus at NIST. "That was definitely not the case."

Countries in Europe and South America adopted the metric system throughout the 19th century. In 1875, delegates from the U.S. and 16 other countries signed the Treaty of the Meter in Paris. It established a universal system of units based on the meter, the kilogram and the second that would streamline trade among nations. (The second was defined as 1/86,400 of the average time it takes for Earth to complete a single rotation on its axis.)

Although the meter and the kilogram were based on the size of Earth, they were officially defined by metal artifacts, including Le Grand K, that were cast in London in 1889 and kept in a vault in the basement of the newly created International Bureau of Weights and Measures in Sevres, France. Member nations received one of 40 precise replicas.

The Treaty of the Meter also established the General Conference on Weights and Measures (CGPM), an international group tasked with studying and voting on proposed changes to units of measurement for all member states.