# The Seven *SI Base Units*

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The SI Brochure, Sections 2.2 and 2.3.1

**The International System of Units, the SI, is the system of units in which**

- **the unperturbed ground state hyperfine transition frequency of the caesium 133 atom, $\Delta\nu_{\mathrm{Cs}}$, is 9 192 631 770 Hz,**
- **the speed of light in vacuum, $c$, is 299 792 458 m/s,**
- **the Planck constant, $h$, is $6.626\,070\,15 \times 10^{-34}$ J s,**
- **the elementary charge, $e$, is $1.602\,176\,634 \times 10^{-19}$ C,**
- **the Boltzmann constant, $k$, is $1.380\,649 \times 10^{-23}$ J/K,**
- **the Avogadro constant, $N_{\mathrm{A}}$, is $6.022\,140\,76 \times 10^{23}$ mol$^{-1}$,**
- **the luminous efficacy of monochromatic radiation of frequency $540 \times 10^{12}$ Hz, $K_{\mathrm{cd}}$, is 683 lm/W,**

where the hertz, joule, coulomb, lumen, and watt, with unit symbols Hz, J, C, lm, and W, respectively, are related to the units second, metre, kilogram, ampere, kelvin, mole, and candela, with unit symbols s, m, kg, A, K, mol, and cd, respectively, according to Hz = s$^{-1}$, J = kg m$^2$ s$^{-2}$, C = A s, lm = cd sr, and W = kg m$^2$ s$^{-3}$.

The numerical values of the seven defining constants have no uncertainty.

The base units of the SI are listed in Table 2.

**Table 2. SI base units**

| Base quantity | | Base unit | |
|---|---|---|---|
| Name | Typical symbol | Name | Symbol |
| time | $t$ | second | s |
| length | $l$, $x$, $r$, etc. | metre | m |
| mass | $m$ | kilogram | kg |
| electric current | $I$, $i$ | ampere | A |
| thermodynamic temperature | $T$ | kelvin | K |
| amount of substance | $n$ | mole | mol |
| luminous intensity | $I_{\mathrm{v}}$ | candela | cd |

Starting from the definition of the SI in terms of fixed numerical values of the defining constants, definitions of each of the seven base units are deduced by using, as appropriate, one or more of these defining constants to give the following set of definitions:

## The second

**The second, symbol s, is the SI unit of time. It is defined by taking the fixed numerical value of the caesium frequency, $\Delta\nu_{\mathrm{Cs}}$, 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$^{-1}$.**

This definition implies the exact relation $\Delta\nu_{\mathrm{Cs}}$ = 9 192 631 770 Hz. Inverting this relation gives an expression for the unit second in terms of the defining constant $\Delta\nu_{\mathrm{Cs}}$:

$$1\ \mathrm{Hz} = \frac{\Delta\nu_{\mathrm{Cs}}}{9\,192\,631\,770} \quad \text{or} \quad 1\ \mathrm{s} = \frac{9\,192\,631\,770}{\Delta\nu_{\mathrm{Cs}}}.$$

The effect of this definition is that the second is equal to the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the unperturbed ground state of the $^{133}$Cs atom.

## The metre

**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 the caesium frequency $\Delta\nu_{\mathrm{Cs}}$.**

This definition implies the exact relation $c$ = 299 792 458 m s$^{-1}$. Inverting this relation gives an exact expression for the metre in terms of the defining constants $c$ and $\Delta\nu_{\mathrm{Cs}}$:

$$1\ \mathrm{m} = \left(\frac{c}{299\,792\,458}\right)\mathrm{s} = \frac{9\,192\,631\,770}{299\,792\,458}\,\frac{c}{\Delta\nu_{\mathrm{Cs}}} \approx 30.663\,319\,\frac{c}{\Delta\nu_{\mathrm{Cs}}}.$$

The effect of this definition is that one metre is the length of the path travelled by light in vacuum during a time interval with duration of 1/299 792 458 of a second.

## The kilogram

**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 $\Delta\nu_{\mathrm{Cs}}$.**

This definition implies the exact relation $h = 6.626\,070\,15 \times 10^{-34}$ kg m$^2$ s$^{-1}$. Inverting this relation gives an exact expression for the kilogram in terms of the three defining constants $h$, $\Delta\nu_{\mathrm{Cs}}$ and $c$:

$$1\ \mathrm{kg} = \left(\frac{h}{6.626\,070\,15 \times 10^{-34}}\right)\mathrm{m}^{-2}\,\mathrm{s}$$

which is equal to

$$1\ \mathrm{kg} = \frac{(299\,792\,458)^2}{(6.626\,070\,15 \times 10^{-34})(9\,192\,631\,770)}\,\frac{h\,\Delta\nu_{\mathrm{Cs}}}{c^2} \approx 1.475\,5214 \times 10^{40}\,\frac{h\,\Delta\nu_{\mathrm{Cs}}}{c^2}.$$

The effect of this definition is to define the unit kg m$^2$ s$^{-1}$ (the unit of both the physical quantities action and angular momentum). Together with the definitions of the second and the metre this leads to a definition of the unit of mass expressed in terms of the Planck constant $h$.

## The ampere

**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 $\Delta\nu_{\mathrm{Cs}}$.**

This definition implies the exact relation $e = 1.602\,176\,634 \times 10^{-19}$ A s. Inverting this relation gives an exact expression for the unit ampere in terms of the defining constants $e$ and $\Delta\nu_{\mathrm{Cs}}$:

$$1\ \mathrm{A} = \left(\frac{e}{1.602\,176\,634 \times 10^{-19}}\right)\mathrm{s}^{-1}$$

which is equal to

$$1\ \mathrm{A} = \frac{1}{(9\,192\,631\,770)(1.602\,176\,634 \times 10^{-19})}\,\Delta\nu_{\mathrm{Cs}}\,e \approx 6.789\,6868 \times 10^{8}\,\Delta\nu_{\mathrm{Cs}}\,e\,.$$

The effect of this definition is that one ampere is the electric current corresponding to the flow of $1/(1.602\,176\,634 \times 10^{-19})$ elementary charges per second.

## The kelvin

**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 $\Delta\nu_{\mathrm{Cs}}$.**

This definition implies the exact relation $k = 1.380\,649 \times 10^{-23}$ kg m$^2$ s$^{-2}$ K$^{-1}$. Inverting this relation gives an exact expression for the kelvin in terms of the defining constants $k$, $h$ and $\Delta\nu_{\mathrm{Cs}}$:

$$1\ \mathrm{K} = \left(\frac{1.380\,649 \times 10^{-23}}{k}\right)\mathrm{kg\,m^2\,s^{-2}}$$

which is equal to

$$1\ \mathrm{K} = \frac{1.380\,649 \times 10^{-23}}{(6.626\,070\,15 \times 10^{-34})\,(9\,192\,631\,770)}\,\frac{\Delta\nu_{\mathrm{Cs}}\,h}{k} \approx 2.266\,6653\,\frac{\Delta\nu_{\mathrm{Cs}}\,h}{k}.$$

The effect of this definition is that one kelvin is equal to the change of thermodynamic temperature that results in a change of thermal energy $kT$ by $1.380\,649 \times 10^{-23}$ J.

## The mole

**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, $N_{\mathrm{A}}$, 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.**

This definition implies the exact relation $N_{\mathrm{A}} = 6.022\,140\,76 \times 10^{23}$ mol$^{-1}$. Inverting this relation gives an exact expression for the mole in terms of the defining constant $N_{\mathrm{A}}$:

$$1\ \mathrm{mol} = \left(\frac{6.022\,140\,76 \times 10^{23}}{N_{\mathrm{A}}}\right).$$

The effect of this definition is that the mole is the amount of substance of a system that contains $6.022\,140\,76 \times 10^{23}$ specified elementary entities.

## The candela

**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 $540 \times 10^{12}$ Hz, $K_{\mathrm{cd}}$, 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 $\Delta\nu_{\mathrm{Cs}}$.**

This definition implies the exact relation $K_{\mathrm{cd}}$ = 683 cd sr kg$^{-1}$ m$^{-2}$ s$^3$ for monochromatic radiation of frequency $\nu$ = 540 × 10$^{12}$ Hz. Inverting this relation gives an exact expression for the candela in terms of the defining constants $K_{\mathrm{cd}}$, $h$ and $\Delta\nu_{\mathrm{Cs}}$:

$$1\ \mathrm{cd} = \left(\frac{K_{\mathrm{cd}}}{683}\right)\mathrm{kg\,m^2\,s^{-3}\,sr^{-1}}$$

which is equal to

$$1\ \mathrm{cd} = \frac{1}{(6.626\,070\,15 \times 10^{-34})\,(9\,192\,631\,770)^2\,683}\,(\Delta\nu_{\mathrm{Cs}})^2\,h\,K_{\mathrm{cd}} \approx 2.614\,8305 \times 10^{10}\,(\Delta\nu_{\mathrm{Cs}})^2\,h\,K_{\mathrm{cd}}\,.$$

The effect of this definition is that one candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency $540 \times 10^{12}$ Hz and has a radiant intensity in that direction of (1/683) W sr$^{-1}$. The definition of the steradian is given below Table 4.

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