

# The LUA-PHYSICAL library

Version 1.0.4

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## Abstract

`lua-physical` is a pure Lua library, which provides functions and objects for the computation of physical quantities. The package has been written, to simplify the creation physics problem sets. The package provides units of the SI and the imperial system. In order to display the numbers with measurement uncertainties, the package is able to perform gaussian error propagation.

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# 1 Introduction

The author of this package is a physics teacher at the high school *Kantonsschule Zug*, Switzerland. The main use of this package is to write physics problem sets. It is possible to integrate physical calculations directly into Lua $\text{\LaTeX}$ . The package has been in use since 2016. Many bugs have been found and fixed. Nevertheless it still is possible, that some were not found yet. Therefore the author recommends not to use this package in industry or science. If one does so, it's the responsibility of the user to check results for plausability. If the user finds some bugs, they can be reported at [github.com](https://github.com).

## 1.1 Dependencies

This is a standalone library. However, it is compatible with the `siunitx` package. The results of calculations can be printed to Lua $\text{\LaTeX}$  by calling the `physical.Quantity.tosiunitx()` method. It is recommended to use a macro for this purpose. The preamble in the next section, simplifies the printing of quantities by the macros `\q{}`, `\qs{}` and `\qu{}`.

## 2 Loading

By calling `require("physical")` the `lua-physical` library is loaded. The following Lua $\text{\LaTeX}$  preamble loads the `lua-physical` package, does some configuration of the `siunitx` package and defines the macros `\q{}`, `\qs{}` and `\qu{}` for printing physical quantities.

Listing 1: basic preamble

```
\usepackage{luacode}
\usepackage{siunitx}

% initialize the lua-physical package
\begin{luacode*}
  physical = require("physical")
  N = physical.Number
\end{luacode*}

% configure the siunitx package
\sisetup{
  output-decimal-marker = {.},
  per-mode = symbol,
  separate-uncertainty = true,
  add-decimal-zero = true,
  exponent-product = \cdot,
  round-mode = off
}

% declare the unitless unit (siunitx package)
\DeclareSIUnit\number{}
```

```

% print a quantity using the \SI{}{} macro.
\newcommand{\q}[1]{%
  \directlua{
    tex.print(
      physical.Quantity.tosiunitx(
        #1,
        "scientific-notation=fixed,exponent-to-prefix=false"
      )
    )
  }%
}

% print a quantity in scientific notation using \SI{}{} macro.
\newcommand{\qs}[1]{%
  \directlua{
    tex.print(
      physical.Quantity.tosiunitx(
        #1,
        "scientific-notation=true,exponent-to-prefix=false,
        round-integer-to-decimal=true"
      )
    )
  }%
}

% print the unit of a quantity using the \si{} macro
\newcommand{\qu}[1]{%
  \directlua{
    tex.print(
      physical.Quantity.tosiunitx(
        #1,
        nil,
        physical.Quantity.SIUNITX_si
      )
    )
  }%
}

```

## 2.1 License

This code is freely distributable under the terms of the MIT license.

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### 3 Usage

Given the basic preamble 1, units can be used in lua code directly. By convention, all units have an underscore in front of them, i.e. meter is `_m`, second is `_s`. For a complete list of all available units, see section 4. The following example illustrates the use of this library.

Listing 2: Velocity of a car.

```
\begin{luacode}
  d = 10 * _m
  t = 2 * _s
  v = d / t
\end{luacode}

A car travels  $\text{\q{d}}$  in  $\text{\q{t}}$ . Calculate its velocity.
%
\begin{equation*}
  v=\frac{d}{t} = \frac{\text{\q{d}}}{\text{\q{t}}} = \underline{\text{\q{v}}}
\end{equation*}
```

A car travels 10 m in 2 s. Calculate its velocity.

$$v = \frac{s}{t} = \frac{10 \text{ m}}{2 \text{ s}} = \underline{5.0 \text{ m/s}}$$

In the above listing 2, the variable `s` stands for displacement and has the unit meter `_m`, the variable `t` stands for time and is given in seconds `_s`. If physical quantities are divided or multiplied, derived quantities are created. In the example problem above, the velocity `v` has the unit `_m/_s`. By using the macro `\q{}` all quantities can be printed to the Lua<sup>A</sup>T<sub>E</sub>X code directly.

#### 3.1 Unit conversion

It is often the case, that the result of a calculation has to be converted to other units. Lets assume, that in the problem of listing 2, the velocity should be determined in `_km/_h`. This can be done using the `:to()` method, which is available on all quantity objects, see 3.

Listing 3: Velocity of a car in kilometers per hour.

```
\begin{luacode}
  d = 10 * _m
  t = 2 * _s
  v = (s / t):to(_km/_h)
\end{luacode}
```

A car travels  $\text{\textbackslash q{d}}$  in  $\text{\textbackslash q{t}}$ . Calculate its velocity in  $\text{\textbackslash qu{km/h}}$ .

```
%
\begin{equation*}
v = \frac{d}{t} = \frac{\text{\textbackslash q{d}}}{\text{\textbackslash q{t}}} = \underline{\text{\textbackslash q{v}}}
\end{equation*}
```

A car travels 10 m in 2 s. Calculate its velocity in km/h.

$$v = \frac{d}{t} = \frac{10 \text{ m}}{2 \text{ s}} = \underline{18.0 \text{ km/h}}$$

Another example is given in listing 4. The task is to calculate the volume of a cuboid. The length of the edges are given in different units. The result of the multiplication has the unit cm mm m. If the unit  $\text{cm}^3$  is preferred, it has to be converted explicitly. At first this looks a bit cumbersome. The reason of this behaviour is, that the software is not able to guess the unit of the result. In many cases, like in the example problem, it's not clear what unit the volume should have. Is it  $\text{m}^3$ ,  $\text{cm}^3$  or  $\text{L}$ ? The user has to give that conversion explicitly.

Listing 4: Volume of a cuboid.

```
\begin{luacode}
a = 12 * _cm
b = 150 * _mm
c = 1.5 * _m

V = ( a * b * c ):to(_dm^3)
\end{luacode}

Find the volume of a rectangular cuboid with lengths  $\text{\textbackslash q{a}}$ ,
 $\text{\textbackslash q{b}}$  and  $\text{\textbackslash q{c}}$ .
%
\begin{equation*}
V = a \cdot b \cdot c
= \text{\textbackslash q{a}} \cdot \text{\textbackslash q{b}} \cdot \text{\textbackslash q{c}}
= \underline{\text{\textbackslash q{V}}}
\end{equation*}
```

Find the volume of a rectangular cuboid with lengths 12 cm, 150 mm and 1.5 m.

$$V = a \cdot b \cdot c = 12 \text{ cm} \cdot 150 \text{ mm} \cdot 1.5 \text{ m} = 27.0 \text{ dm}^3 = \underline{27.0 \text{ dm}^3}$$

The `siunitx` package has definitions for all SI units plus some non-SI units. If a quantity has a unit, which is not defined by the `siunitx` package, it has to be declared using the `\DeclareSIUnit` macro.

Listing 5: Non-SI units.

```
% add this declaration to the preamble
\DeclareSIUnit\inch{in}

% document
\begin{luacode}
  l = 12 * _in
\end{luacode}

Convert $\q{1}$ to the unit $\qu{cm}$.
%
\begin{equation*}
  l = \q{1} \cdot \frac{\q{in:to(cm)}}{\qu{in}} = \q{1:to(cm)}
\end{equation*}
```

Convert 12 in (inches) to the unit cm.

$$l = 12 \text{ in} \cdot \frac{2.54 \text{ cm}}{\text{in}} = \underline{30.48 \text{ cm}}$$

### 3.1.1 Temperature Conversion

Most physical units transform linearly. Exceptions are temperature units like degree Celsius `_degC` and degree Fahrenheit `_degF`. These units are ambiguous and can be interpreted as temperature differences or as absolute temperatures. In the latter case, the conversion to base units is not a linear, but an affine transformation. This is because degree Celsius and degree Fahrenheit scales have their zero points at different temperatures compared to the unit Kelvin.

By default `_degC` and `_degF` units are temperature differences. If one wants to have it converted absolutely, it has to be done adding / subtracting `_degC_0 = 273.15*_K` or `_degF_0 = (273.15 - 32*(5/9)) *_K`, the zero point temperatures of the scales.

In the following problem, listing 6, the task is to convert temperatures given in the unit degree Celsius and degree Fahrenheit to Kelvin.

Listing 6: Temperature conversion.

```
\begin{luacode}
  theta_1 = 110 * _degC
  T_1 = ( theta_1 + _degC_0 ):to(_K)

  T_2 = 100 * _K
  theta_2 = ( T_2 - _degC_0 ):to(_degC)

  theta_3 = 212 * _degF
  T_3 = ( theta_3 + _degF_0 ):to(_K)
```



```

T_4 = 100 * _K
theta_4 = ( T_4 - _degF_0 ):to(_degF)

theta_5 = 100 * _degC
theta_6 = ( ( theta_5 + _degC_0 ):to(_K) - _degF_0 ):to(_degF)
\end{luacode}

\begin{align*}
\q{theta_1} & \mathrel{\widehat{=}} \q{T_1} \\
\q{theta_2} & \mathrel{\widehat{=}} \q{T_2} \\
\q{theta_3} & \mathrel{\widehat{=}} \q{T_3} \\
\q{theta_4} & \mathrel{\widehat{=}} \q{T_4} \\
\q{theta_5} & \mathrel{\widehat{=}} \q{theta_6}
\end{align*}

```

$$\begin{aligned}
110\text{ }^{\circ}\text{C} &\hat{=} 383.15\text{ K} \\
-173.15\text{ }^{\circ}\text{C} &\hat{=} 100\text{ K} \\
212\text{ }^{\circ}\text{F} &\hat{=} 373.15\text{ K} \\
-279.67\text{ }^{\circ}\text{F} &\hat{=} 100\text{ K} \\
100\text{ }^{\circ}\text{C} &\hat{=} 212.0\text{ }^{\circ}\text{F}
\end{aligned}$$

### 3.2 Uncertainty Propagation

The `lua-physical` library supports uncertainty propagation. To create a number with an uncertainty, an instance of `physical.Number` has to be created. It has to be remembered, that `N` is a alias for `physical.Number`. The first argument of the constructor `N(mean, uncertainty)` is the mean value and the second one the uncertainty of the measurement.

For the uncertainty propagation the gaussian formula

$$\Delta f = \sqrt{\left(\frac{\partial f}{\partial x_1} \cdot \Delta x_1\right)^2 + \dots + \left(\frac{\partial f}{\partial x_n} \cdot \Delta x_n\right)^2}$$

is used. This formula is a good estimation for the uncertainty  $\Delta f$ , if the quantities  $x_1, \dots, x_n$  the function  $f$  depends on, have no correlation. Further, the function  $f$  has to change linearly, if quantities  $x_i$  are changed in the range of their uncertainties.

The example in listing 7 shows the usage of `N()`. At the definition of the distance and the speed of light, the constants are given with full precision, i.e. The distance `_au` is 149 597 870.7 km and `_c` is 299 792.458 km/s. By multipling these quantities with `N(1,0.0001)` the precision is reduced. The uncertainty propagation takes

care of rounding the resulting time `t` to the correct precision. For printing, the macro `\qs{}` for scientific notation is used.

Listing 7: Time of flight.

```
\begin{luacode}
  d = N(1,0.0001) * ( _au ):to(_km)
  v = N(1,0.0001) * ( _c ):to(_km/_s)
  t = ( d/v ):to(_min)
\end{luacode}

Calculate the time, a lightray travels from the surface of the sun to
the earth.
The mean distance from the sun to the eart is  $\text{\qs{d}}$ . The speed of
light is  $\text{\qs{v}}$ .

%
\begin{equation*}
  t = \frac{d}{v} = \frac{\text{\q{d}}}{\text{\q{v}}} = \underline{\text{\q{t}}}
\end{equation*}
```

Calculate the time, a lightray travels from the surface of the sun to the earth. The mean distance from the sun to the eart is  $1.496 \cdot 10^8$  km. The speed of light is  $2.998 \cdot 10^5$  km/s.

$$t = \frac{d}{v} = \frac{1.496 \cdot 10^8 \text{ km}}{2.998 \cdot 10^5 \text{ km/s}} = \underline{8.32 \text{ min}}$$

Another example is given in listing 8, the task is to find the volume of an ideal gas. Given are pressure `p` in `_bar`, amount of substance `n` in `_mol` and absolute temperature `T` in degree celsius `_degC`.

Listing 8: Volume of an ideal gas.

```
\begin{luacode}
  N.omitUncertainty = true

  p = N(1.013,0.0001) * _bar
  n = N(1,0.01) * _mol
  T = N(30,0.1) * _degC

  V = ( n * _R * (T + _degC_0):to(_K) / p ):to(_L)
\end{luacode}

An ideal gas ( $\text{\q{n}}$ ) has a pressure of  $\text{\q{p}}$  and a temperature of  $\text{\q{T}}$ . Calculate the volume of the gas.

%
\begin{equation*}
  V = \frac{\text{\q{n}} \cdot \text{\q{R}} \cdot \text{\q{(T + _degC_0):to(_K)}}}{\text{\q{p}}} = \text{\q{V}}
\end{equation*}
```

```
= \underline{\q{V}}
\end{equation*}
```

An ideal gas (1.0 mol) has a pressure of 1.013 bar and a temperature of 30 °C. Calculate the volume of the gas.

$$V = \frac{1.0 \text{ mol} \cdot 8.31 \text{ J}/(\text{mol K}) \cdot 303 \text{ K}}{1.013 \text{ bar}} = \underline{25 \text{ L}}$$

This example shows, that the result has only two digits. If more digits are needed, the uncertainties of the given quantities should be made smaller.

### 3.2.1 Print the Uncertainty explicitly

It is possible to print the uncertainty explicitly. By default the parameter `N.omitUncertainty` is set to `true`. In listing 9 it is set to `false` and the uncertainty is printed.

Listing 9: Uncertainty in area calculation.

```
\begin{luacode}
  N.omitUncertainty = false

  a = N(2,0.1) * _m
  b = N(3,0.1) * _m

  A = ( a * b ):to(_m^2)
\end{luacode}

Calculate the area of a rectangle with lengths $\q{a}$ and $\q{b}$.
%
\begin{equation*}
  A = a \cdot b
  = \q{a} \cdot \q{b}
  = \underline{\q{A}}
\end{equation*}
```

Calculate the area of a rectangle with lengths  $(2.00 \pm 0.10) \text{ m}$  and  $(3.00 \pm 0.10) \text{ m}$ .

$$A = a \cdot b = (2.00 \pm 0.10) \text{ m} \cdot (3.00 \pm 0.10) \text{ m} = \underline{(6.0 \pm 0.4) \text{ m}^2}$$

### 3.3 Mathematical operations

Two physical quantities with identical dimensions can be added or subtracted. The library checks the validity of those operations and throws an error if two addends haven't the same dimensions.

Listing 10: Addition and subtraction

```
l_1 = 1 * _m
l_2 = 2 * _cm
t = 2 * _s

l_1 + t
Error: Cannot add '1* _m' to '2 * _s', because they have different
dimensions.

l_1 + l_2
102.0 * _cm
```

New physical quantities can be created by division and multiplication. As long as no division by zero is made, no errors should occur.

Listing 11: Multiplication and Division

```
l_1 = 1 * _m
l_2 = 2 * _cm

(l_1 * l_2):to(_m^2)
0.02 * _m^2

(l_1 / l_2):to(_1)
50.0 * _1
```

Physical quantities can be exponentiated. The library doesn't check, if the result has units with non integer exponents.

Listing 12: Exponentiation

```
l = 5 * _m
A = l^2

A:to(_m^2)
25.0 * _m^2

A:sqrt()
5.0 * _m

A^0.5
5.0 * _m
```

Exponential functions and the logarithms should have dimensionless arguments. The library throws an error if that's not the case.

Listing 13: Exponential function and logarithm

```
N_0 = 1000 * _1
lambda = Q.log(2)/(2*_h)
t = 50 * _min

N_0 * Q.exp(-lambda * t)
749.15353843834 * _1
```

## 4 Supported Units

All supported units are listed in this section. Subsection 4.2 lists the seven base units of the International System of Units (SI). In subsection 4.3 mathematical and physical constants are defined. The subsection 4.4 contains all coherent derived units from the SI system and 4.5 those which are accepted to use with the SI. The subsection 4.6 lists nominal astronomical units, which are proposed by [4]. Subsection 4.7 lists units, which are common but outside of the SI system. The subsections 4.8 and 4.9 are dedicated to imperial and U.S. customary units. The last subsection 4.10 contains international currencies.

### 4.1 Prefixes

All SI units have prefixed versions, i.e. `_us` microsecond, `_cm` centimeter, `_mN` millinewton, see table 1. Some units of data processing, like `_bit` have prefixes which are powers of 2. They are called binary or IEC prefixes, see table 2 [2, 121].

| Prefix | Symbol | Definition | Prefix | Symbol | Definition |
|--------|--------|------------|--------|--------|------------|
| yotta  | Y      | 1e24       | deci   | d      | 1e-1       |
| zetta  | Z      | 1e21       | centi  | c      | 1e-2       |
| exa    | E      | 1e18       | milli  | m      | 1e-3       |
| peta   | P      | 1e15       | micro  | u      | 1e-6       |
| tera   | T      | 1e12       | nano   | n      | 1e-9       |
| giga   | G      | 1e9        | pico   | p      | 1e-12      |
| mega   | M      | 1e6        | femto  | f      | 1e-15      |
| kilo   | k      | 1e3        | atto   | a      | 1e-18      |
| hecto  | h      | 1e2        | zepto  | z      | 1e-21      |
| deca   | da     | 1e1        | yocto  | y      | 1e-23      |

Table 1: SI prefixes [2, 121]

| Prefix | Symbol | Definition                |
|--------|--------|---------------------------|
| kibi   | Ki     | 1024                      |
| mebi   | Mi     | 1048576                   |
| gibi   | Gi     | 1073741824                |
| tebi   | Ti     | 1099511627776             |
| pebi   | Pi     | 1125899906842624          |
| exbi   | Ei     | 1152921504606846976       |
| zebi   | Zi     | 1180591620717411303424    |
| yobi   | Yi     | 1208925819614629174706176 |

Table 2: IEC prefixes [2, 121]

## 4.2 Base Units

The `lua-physical` library has nine base quantities. These are the seven basis units or basis quantities of the SI system [3] and in addition the base quantity of information `_bit` and of currency `_EUR`. All other quantities are derived from these base units.

| Quantity            | Unit   | Symbol          | Dim. | Definition  |
|---------------------|--------|-----------------|------|---|
| number <sup>1</sup> | –      | <code>_1</code> | 1    | The dimensionless number one.   |
| time                | second | <code>_s</code> | T    | 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 1/s. |
| length              | meter  | <code>_m</code> | L    | 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 of m/s.   |

<sup>1</sup>The number one is a unit with dimension zero. Stricly speaking it is not a base unit.

| Quantity                  | Unit     | Symbol            | Dim.           | Definition   |
|---------------------------|----------|-------------------|----------------|--|
| mass                      | kilogram | <code>_kg</code>  | M              | The SI unit of mass. It is defined by taking the fixed numerical value of the Planck constant $h$ to be $6.626\,070\,15 \cdot 10^{-34}$ when expressed in $\text{m}^2 \text{kg/s}$ .   |
| electric current          | ampere   | <code>_A</code>   | I              | The SI unit of electric current. It is defined by taking the fixed numerical value of the elementary charge $e$ to be $1.602\,176\,634 \cdot 10^{-19}$ when expressed in A s.  |
| thermodynamic temperature | kelvin   | <code>_K</code>   | K <sup>1</sup> | The SI unit of the thermodynamic temperature. It is defined by taking the fixed numerical value of the Boltzmann constant $k_B$ to be $1.380\,649 \cdot 10^{-23}$ when expressed in $\text{kg m}^2/(\text{s}^2 \text{K})$  |
| amount of substance       | mole     | <code>_mol</code> | N              | The SI unit of amount of substance. One mole contains exactly $6.022\,140\,76 \cdot 10^{23}$ elementary entities. This number is the fixed numerical value of the Avogadro constant $N_A$ when expressed in $1/\text{mol}$ .   |
| luminous intensity        | candela  | <code>_cd</code>  | J              | 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 $5.4 \cdot 10^{14} \text{ Hz}$ , $K_{cd}$ , to be 683 when expressed in the unit $\text{cd sr s}^3/(\text{kg m}^2)$ . |
| information               | bit      | <code>_bit</code> | B              | The smallest amount of information.  |
| currency                  | euro     | <code>_EUR</code> | C              | The value of the currency Euro.  |

Table 3: Base units

<sup>1</sup>The SI symbol for the dimension of temperature is  $\Theta$ , but all symbols of this library consist of roman letters, numbers and underscores only. Therefore the symbol for the dimension of the thermodynamic temperature is the letter K.



### 4.3 Constants

All physical constants are taken from the NIST webpage [1].

| Name                    | Symbol               | Definition   |
|-------------------------|----------------------|--|
| pi                      | <code>_Pi</code>     | $3.1415926535897932384626433832795028841971 * \_1$ |
| eulersnumber            | <code>_E</code>      | $2.7182818284590452353602874713526624977572 * \_1$ |
| speedoflight            | <code>_c</code>      | $299792458 * \_m/\_s$                              |
| gravitationalconstant   | <code>_Gc</code>     | $N(6.67408e-11, 3.1e-15) * \_m^3/(\_kg*\_s^2)$     |
| planckconstant          | <code>_h_P</code>    | $6.62607015e-34 * \_J*\_s$                         |
| reducedplanckconstant   | <code>_h_Pbar</code> | $\_h\_P/(2*\_Pi)$                                  |
| elementarycharge        | <code>_e</code>      | $1.602176634e-19 * \_C$                            |
| vacuumpermeability      | <code>_u_0</code>    | $4e-7*\_Pi * \_N/\_A^2$                            |
| vacuumpermittivity      | <code>_e_0</code>    | $1/(\_u\_0*\_c^2)$                                 |
| atomicmassunit          | <code>_u</code>      | $N(1.66053904e-27, 2e-35) * \_kg$                  |
| electronmass            | <code>_m_e</code>    | $N(9.10938356e-31, 1.1e-38) * \_kg$                |
| protonmass              | <code>_m_p</code>    | $N(1.672621898e-27, 2.1e-35) * \_kg$               |
| neutronmass             | <code>_m_n</code>    | $N(1.674927471e-27, 2.1e-35) * \_kg$               |
| bohrmagneton            | <code>_u_B</code>    | $\_e*\_h\_Pbar/(2*\_m\_e)$                         |
| nuclearmagneton         | <code>_u_N</code>    | $\_e*\_h\_Pbar/(2*\_m\_p)$                         |
| electronmagneticmoment  | <code>_u_e</code>    | $N(-928.4764620e-26, 5.7e-32) * \_J/\_T$           |
| protonmagneticmoment    | <code>_u_p</code>    | $N(1.4106067873e-26, 9.7e-35) * \_J/\_T$           |
| neutronmagneticmoment   | <code>_u_n</code>    | $N(-0.96623650e-26, 2.3e-26) * \_J/\_T$            |
| finestructureconstant   | <code>_alpha</code>  | $\_u\_0*\_e^2*\_c/(2*\_h\_P)$                      |
| rydbergconstant         | <code>_Ry</code>     | $\_alpha^2*\_m\_e*\_c/(2*\_h\_P)$                  |
| avogadronumber          | <code>_N_A</code>    | $6.02214076e23/\_mol$                              |
| boltzmannconstant       | <code>_k_B</code>    | $1.380649e-23 * \_J/\_K$                           |
| molargasconstant        | <code>_R</code>      | $N(8.3144598, 4.8e-6) * \_J/(\_K*\_mol)$           |
| stefanboltzmannconstant | <code>_sigma</code>  | $\_Pi^2*\_k\_B^4/(60*\_h\_Pbar^3*\_c^2)$           |
| standardgravity         | <code>_g_0</code>    | $9.80665 * \_m/\_s^2$                              |

Table 4: Physical and mathematical constants

## 4.4 Coherent derived units in the SI

All units in this section are coherent derived units from the SI base units with special names, [2, 118].

| Quantity                          | Unit      | Symbol             | Definition               |
|-----------------------------------|-----------|--------------------|--------------------------|
| Plane Angle <sup>1</sup>          | radian    | <code>_rad</code>  | <code>_1</code>          |
| Solid Angle <sup>2</sup>          | steradian | <code>_sr</code>   | <code>_rad^2</code>      |
| Frequency                         | hertz     | <code>_Hz</code>   | <code>1/_s</code>        |
| Force                             | newton    | <code>_N</code>    | <code>_kg*_m/_s^2</code> |
| Pressure                          | pascal    | <code>_Pa</code>   | <code>_N/_m^2</code>     |
| Energy                            | joule     | <code>_J</code>    | <code>_N*_m</code>       |
| Power                             | watt      | <code>_W</code>    | <code>_J/_s</code>       |
| Electric Charge                   | coulomb   | <code>_C</code>    | <code>_A*_s</code>       |
| Electric Potential                | volt      | <code>_V</code>    | <code>_J/_C</code>       |
| Electric Capacitance              | farad     | <code>_F</code>    | <code>_C/_V</code>       |
| Electric Resistance               | ohm       | <code>_Ohm</code>  | <code>_V/_A</code>       |
| Electric Conductance <sup>3</sup> | siemens   | <code>_S</code>    | <code>_A/_V</code>       |
| Magnetic Flux                     | weber     | <code>_Wb</code>   | <code>_V*_s</code>       |
| Magnetic Flux Density             | tesla     | <code>_T</code>    | <code>_Wb/_m^2</code>    |
| Inductance                        | henry     | <code>_H</code>    | <code>_Wb/_A</code>      |
| Temperature <sup>4</sup>          | celsius   | <code>_degC</code> | <code>_K</code>          |
| Luminous Flux                     | lumen     | <code>_lm</code>   | <code>_cd*_sr</code>     |
| Illuminance                       | lux       | <code>_lx</code>   | <code>_lm/_m^2</code>    |
| Activity                          | becquerel | <code>_Bq</code>   | <code>1/_s</code>        |
| Absorbed Dose                     | gray      | <code>_Gy</code>   | <code>_J/_kg</code>      |
| Dose Equivalent                   | sievert   | <code>_Sv</code>   | <code>_J/_kg</code>      |
| Catalytic Activity                | katal     | <code>_kat</code>  | <code>_mol/_s</code>     |

<sup>1</sup>In the SI system, the quantity Plane Angle has the dimension of a number.

<sup>2</sup>In the SI system, the quantity Solid Angle has the dimension of a number.

<sup>3</sup>The unit `_PS` stands for peta siemens and is in conflict with the metric version of the unit horsepower (german *Pferdestärke*). Since the latter is more common than peta siemens, `_PS` is defined to be the metric version of horsepower.

<sup>4</sup>The unit `_degC` is by default interpreted as a temperature difference.

## 4.5 Non-SI units accepted for use with the SI

There are a few units with dimension 1. [2, 124].

| Quantity    | Unit      | Symbol                | Definition                         |
|-------------|-----------|-----------------------|------------------------------------|
| Time        | minute    | <code>_min</code>     | $60 * \text{\_s}$                  |
|             | hour      | <code>_h</code>       | $60 * \text{\_min}$                |
|             | day       | <code>_d</code>       | $24 * \text{\_h}$                  |
| Plane Angle | degree    | <code>_deg</code>     | $(\text{\_Pi}/180) * \text{\_rad}$ |
|             | arcminute | <code>_arcmin</code>  | $\text{\_deg}/60$                  |
|             | arcsecond | <code>_arcsec</code>  | $\text{\_arcmin}/60$               |
| Area        | hectare   | <code>_hectare</code> | $1e4 * \text{\_m}^2$               |
| Volume      | liter     | <code>_L</code>       | $1e-3 * \text{\_m}^3$              |
| Mass        | tonne     | <code>_t</code>       | $1e3 * \text{\_kg}$                |

## 4.6 Nominal Astronomical Units

The nominal values of solar, terrestrial and jovial quantities are taken from IAU Resolution B3 [4].

| Quantity       | Unit                              | Symbol                 | Definition                                      |
|----------------|-----------------------------------|------------------------|---|
| Length         | <code>nomsolradius</code>         | <code>_R_S_nom</code>  | $6.957e8 * \text{\_m}$                          |
| Irradiance     | <code>nomsolirradiance</code>     | <code>_S_S_nom</code>  | $1361 * \text{\_W}/\text{\_m}^2$                |
| Radiant Flux   | <code>nomsolluminosity</code>     | <code>_L_S_nom</code>  | $3.828e26 * \text{\_W}$                         |
| Temperature    | <code>nomsolefttemperature</code> | <code>_T_S_nom</code>  | $5772 * \text{\_K}$                             |
| Mass Parameter | <code>nomsolmassparameter</code>  | <code>_GM_S_nom</code> | $1.3271244e20 * \text{\_m}^3 * \text{\_s}^{-2}$ |
| Length         | <code>nomterreqradius</code>      | <code>_Re_E_nom</code> | $6.3781e6 * \text{\_m}$                         |
| Length         | <code>nomterrpolarradius</code>   | <code>_Rp_E_nom</code> | $6.3568e6 * \text{\_m}$                         |
| Mass Parameter | <code>nomterrmassparameter</code> | <code>_GM_E_nom</code> | $3.986004e14 * \text{\_m}^3 * \text{\_s}^{-2}$  |
| Length         | <code>nomjoveqradius</code>       | <code>_Re_J_nom</code> | $7.1492e7 * \text{\_m}$                         |
| Length         | <code>nomjovpolarradius</code>    | <code>_Rp_J_nom</code> | $6.6854e7 * \text{\_m}$                         |
| Mass Parameter | <code>nomjovmassparameter</code>  | <code>_GM_J_nom</code> | $1.2668653e17 * \text{\_m}^3 * \text{\_s}^{-2}$ |

## 4.7 Other Non-SI units

The unit Bel is only available with prefix decibel, because `_B` is the unit byte.

| Quantity    | Unit                  | Symbol                 | Definition                           |
|-------------|-----------------------|------------------------|--------------------------------------|
| Length      | angstrom              | <code>_angstrom</code> | $1\text{e-}10 * \text{\_m}$          |
|             | fermi                 | <code>_fermi</code>    | $1\text{e-}15 * \text{\_m}$          |
| Time        | svedberg              | <code>_svedberg</code> | $1\text{e-}13 * \text{\_s}$          |
|             | week                  | <code>_wk</code>       | $7 * \text{\_d}$                     |
|             | year                  | <code>_a</code>        | $365.25 * \text{\_d}$                |
|             | astronomicalunit      | <code>_au</code>       | $149597870700 * \text{\_m}$          |
|             | lightsecond           | <code>_ls</code>       | $\text{\_c} * \text{\_s}$            |
|             | lightyear             | <code>_ly</code>       | $\text{\_c} * \text{\_a}$            |
|             | parsec                | <code>_pc</code>       | $(648000/\text{\_Pi}) * \text{\_au}$ |
| Area        | barn                  | <code>_barn</code>     | $1\text{e-}28 * \text{\_m}^2$        |
|             | are                   | <code>_are</code>      | $1\text{e}2 * \text{\_m}^2$          |
| Volume      | metricteaspoon        | <code>_tsp</code>      | $5\text{e-}3 * \text{\_L}$           |
|             | metrictablespoon      | <code>_Tbsp</code>     | $3 * \text{\_tsp}$                   |
| Plane Angle | gradian               | <code>_gon</code>      | $(\text{\_Pi}/200) * \text{\_rad}$   |
|             | turn                  | <code>_tr</code>       | $2 * \text{\_Pi} * \text{\_rad}$     |
| Solid Angle | spat                  | <code>_sp</code>       | $4 * \text{\_Pi} * \text{\_sr}$      |
| Force       | kilopond              | <code>_kp</code>       | $\text{\_kg} * \text{\_g}_0$         |
| Pressure    | bar                   | <code>_bar</code>      | $1\text{e}5 * \text{\_Pa}$           |
|             | standardatmosphere    | <code>_atm</code>      | $101325 * \text{\_Pa}$               |
|             | technicalatmosphere   | <code>_at</code>       | $\text{\_kp}/\text{\_cm}^2$          |
|             | millimeterofmercury   | <code>_mmHg</code>     | $133.322387415 * \text{\_Pa}$        |
|             | torr                  | <code>_Torr</code>     | $(101325/760) * \text{\_Pa}$         |
| Energy      | thermochemicalcalorie | <code>_cal</code>      | $4.184 * \text{\_J}$                 |
|             | internationalcalorie  | <code>_cal_IT</code>   | $4.1868 * \text{\_J}$                |
|             | gramoftnt             | <code>_g_TNT</code>    | $1\text{e}3 * \text{\_cal}$          |
|             | tonoftnt              | <code>_t_TNT</code>    | $1\text{e}9 * \text{\_cal}$          |

| Quantity                     | Unit                | Symbol                 | Definition                      |
|------------------------------|---------------------|------------------------|---------------------------------|
|                              | electronvolt        | <code>_eV</code>       | <code>_e*_V</code>              |
|                              | wattsecond          | <code>_Ws</code>       | <code>_W*_s</code>              |
|                              | watthour            | <code>_Wh</code>       | <code>_W*_h</code>              |
| Power                        | voltampere          | <code>_VA</code>       | <code>_V*_A</code>              |
| Electric Charge              | amperesecond        | <code>_As</code>       | <code>_A*_s</code>              |
|                              | amperehour          | <code>_Ah</code>       | <code>_A*_h</code>              |
| Information                  | nibble              | <code>_nibble</code>   | <code>4 *_bit</code>            |
|                              | byte                | <code>_B</code>        | <code>8 *_bit</code>            |
| Information<br>Transfer Rate | bitpersecond        | <code>_bps</code>      | <code>_bit/_s</code>            |
| Number                       | percent             | <code>_percent</code>  | <code>1e-2 *_1</code>           |
|                              | permille            | <code>_permille</code> | <code>1e-3 *_1</code>           |
|                              | partspermillion     | <code>_ppm</code>      | <code>1e-6 *_1</code>           |
|                              | partsperbillion     | <code>_ppb</code>      | <code>1e-9 *_1</code>           |
|                              | partspertrillion    | <code>_ppt</code>      | <code>1e-12 *_1</code>          |
|                              | partsperquadrillion | <code>_ppq</code>      | <code>1e-15 *_1</code>          |
|                              | decibel             | <code>_dB</code>       | <code>_1</code>                 |
| Power                        | metrichorsepower    | <code>_PS</code>       | <code>75 *_g_0*_kg*_m/_s</code> |
| Activity                     | curie               | <code>_Ci</code>       | <code>3.7e10 *_Bq</code>        |
| Absorbed Dose                | rad                 | <code>_Rad</code>      | <code>1e-2 *_Gy</code>          |
| Dose Equivalent              | rem                 | <code>_rem</code>      | <code>1e-2 *_Sv</code>          |
| Viscosity                    | poiseuille          | <code>_Pl</code>       | <code>_Pa*_s</code>             |

## 4.8 Imperial Units

| Quantity               | Unit           | Symbol              | Definition                   |
|------------------------|----------------|---------------------|------------------------------|
| Length                 | inch           | <code>_in</code>    | $2.54\text{e-}2 * \text{_m}$ |
|                        | thou           | <code>_th</code>    | $1\text{e-}3 * \text{_in}$   |
| DTP Point <sup>1</sup> | point          | <code>_pt</code>    | $\text{_in}/72$              |
|                        | pica           | <code>_pica</code>  | $12 * \text{_pt}$            |
|                        | hand           | <code>_hh</code>    | $4 * \text{_in}$             |
|                        | foot           | <code>_ft</code>    | $12 * \text{_in}$            |
|                        | yard           | <code>_yd</code>    | $3 * \text{_ft}$             |
|                        | rod            | <code>_rd</code>    | $5.5 * \text{_yd}$           |
|                        | chain          | <code>_ch</code>    | $4 * \text{_rd}$             |
|                        | furlong        | <code>_fur</code>   | $10 * \text{_ch}$            |
|                        | mile           | <code>_mi</code>    | $8 * \text{_fur}$            |
|                        | league         | <code>_lea</code>   | $3 * \text{_mi}$             |
|                        | nauticalmile   | <code>_nmi</code>   | $1852 * \text{_m}$           |
|                        | nauticalleague | <code>_nlea</code>  | $3 * \text{_nmi}$            |
|                        | cable          | <code>_cbl</code>   | $0.1 * \text{_nmi}$          |
|                        | fathom         | <code>_ftm</code>   | $6 * \text{_ft}$             |
| Velocity               | knot           | <code>_kn</code>    | $\text{_nmi}/\text{_h}$      |
| Area                   | acre           | <code>_ac</code>    | $10 * \text{_ch}^2$          |
| Volume                 | gallon         | <code>_gal</code>   | $4.54609 * \text{_L}$        |
|                        | quart          | <code>_qt</code>    | $\text{_gal}/4$              |
|                        | pint           | <code>_pint</code>  | $\text{_qt}/2$               |
|                        | cup            | <code>_cup</code>   | $\text{_pint}/2$             |
|                        | gill           | <code>_gi</code>    | $\text{_pint}/4$             |
|                        | fluidounce     | <code>_fl_oz</code> | $\text{_gi}/5$               |
|                        | fluidram       | <code>_fl_dr</code> | $\text{_fl_oz}/8$            |

<sup>1</sup>The desktop publishing point or PostScript point is 1/72 of an international inch.

| Quantity                 | Unit                     | Symbol               | Definition                                    |
|--------------------------|--------------------------|----------------------|---|
| Mass                     | grain                    | <code>_gr</code>     | $64.79891 * \text{mg}$                        |
|                          | pound                    | <code>_lb</code>     | $7000 * \text{gr}$                            |
|                          | ounce                    | <code>_oz</code>     | $\text{lb}/16$                                |
|                          | dram                     | <code>_dr</code>     | $\text{lb}/256$                               |
|                          | stone                    | <code>_st</code>     | $14 * \text{lb}$                              |
|                          | quarter                  | <code>_qtr</code>    | $2 * \text{st}$                               |
|                          | hundredweight            | <code>_cwt</code>    | $4 * \text{qtr}$                              |
|                          | longton                  | <code>_ton</code>    | $20 * \text{cwt}$                             |
|                          | troy pound               | <code>_lb_t</code>   | $5760 * \text{gr}$                            |
|                          | troy ounce               | <code>_oz_t</code>   | $\text{lb}_t/12$                              |
|                          | pennyweight              | <code>_dwt</code>    | $24 * \text{gr}$                              |
|                          | firkin                   | <code>_fir</code>    | $56 * \text{lb}$                              |
| Time                     | sennight                 | <code>_sen</code>    | $7 * \text{d}$                                |
|                          | fortnight                | <code>_ftn</code>    | $14 * \text{d}$                               |
| Temperature <sup>1</sup> | fahrenheit               | <code>_degF</code>   | $(5/9) * \text{K}$                            |
| Force                    | poundforce               | <code>_lbf</code>    | $\text{lb} * \text{g}_0$                      |
|                          | poundal                  | <code>_pdl</code>    | $\text{lb} * \text{ft} / \text{s}^2$          |
| Mass                     | slug                     | <code>_slug</code>   | $\text{lbf} * \text{s}^2 / \text{ft}$         |
| Pressure                 | poundforcepersquareinch  | <code>_psi</code>    | $\text{lbf} / \text{in}^2$                    |
| Energy, Torque           | thchembritishthermalunit | <code>_BTU</code>    | $(1897.83047608/1.8) * \text{J}$              |
| Energy, Torque           | intbritishthermalunit    | <code>_BTU_it</code> | $1055.05585262 * \text{J}$                    |
| Power                    | horsepower               | <code>_hp</code>     | $33000 * \text{ft} * \text{lbf} / \text{min}$ |

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<sup>1</sup>The unit `_degF` is by default interpreted as a temperature difference.

## 4.9 U.S. customary units

In the U.S., the length units are bound to the meter differently than in the imperial system. The following definitions are taken from [https://en.wikipedia.org/wiki/United\\_States\\_customary\\_units](https://en.wikipedia.org/wiki/United_States_customary_units).

| Quantity | Unit            | Symbol    | Definition       |
|----------|-----------------|-----------|------------------|
| Length   | ussurveyinch    | _in_US    | _m/39.37         |
|          | ussurveyhand    | _hh_US    | 4 * _in_US       |
|          | ussurveyfoot    | _ft_US    | 3 * _hh_US       |
|          | ussurveylink    | _li_US    | 0.66 * _ft_US    |
|          | ussurveyyard    | _yd_US    | 3 * _ft_US       |
|          | ussurveyrod     | _rd_US    | 5.5 * _yd_US     |
|          | ussurveychain   | _ch_US    | 4 * _rd_US       |
|          | ussurveyfurlong | _fur_US   | 10 * _ch_US      |
|          | ussurveymile    | _mi_US    | 8 * _fur_US      |
|          | ussurveyleague  | _lea_US   | 3 * _mi_US       |
|          | ussurveyfathom  | _ftm_US   | 72 * _in_US      |
|          | ussurveycable   | _cbl_US   | 120 * _ftm_US    |
| Area     | ussurveyacre    | _ac_US    | _ch_US * _fur_US |
| Volume   | usgallon        | _gal_US   | 231 * _in^3      |
|          | usquart         | _qt_US    | _gal_US/4        |
|          | uspint          | _pint_US  | _qt_US/2         |
|          | uscup           | _cup_US   | _pint_US/2       |
|          | usgill          | _gi_US    | _pint_US/4       |
|          | usfluidounce    | _fl_oz_US | _gi_US/4         |
|          | ustablespoon    | _Tbsp_US  | _fl_oz_US/2      |
|          | usteaspoon      | _tsp_US   | _Tbsp_US/3       |
|          | usfluid dram    | _fl_dr_US | _fl_oz_US/8      |
| Mass     | usquarter       | _qtr_US   | 25 * _lb         |
|          | ushundredweight | _cwt_US   | 4 * _qtr_US      |
|          | uston           | _ton_US   | 20 * _cwt_US     |



## 4.10 International Currencies

International currency units based on exchange rates from 7.3.2019, 21:00 UTC.

| Name               | Symbol | Definition               |
|--------------------|--------|--------------------------|
| AfghanAfghani      | _AFN   | $0.012 * \text{\_EUR}$   |
| AfghanPul          | _cAFN  | $0.01 * \text{\_AFN}$    |
| AlbanianLek        | _ALL   | $0.008 * \text{\_EUR}$   |
| ArmenianDram       | _AMD   | $0.0018 * \text{\_EUR}$  |
| ArmenianLuma       | _cAMD  | $0.01 * \text{\_AMD}$    |
| AngolanKwanza      | _AOA   | $0.0028 * \text{\_EUR}$  |
| AngolanCentimo     | _cAOA  | $0.01 * \text{\_AOA}$    |
| ArgentinePeso      | _ARS   | $0.021 * \text{\_EUR}$   |
| ArgentineCentavo   | _cARS  | $0.01 * \text{\_ARS}$    |
| AustralianDollar   | _AUD   | $0.63 * \text{\_EUR}$    |
| AustralianCent     | _cAUD  | $0.01 * \text{\_AUD}$    |
| AzerbaijaniManat   | _AZN   | $0.63 * \text{\_EUR}$    |
| AzerbaijaniQepik   | _cAZN  | $0.01 * \text{\_AZN}$    |
| BosnianMark        | _BAM   | $0.51 * \text{\_EUR}$    |
| BosnianFenings     | _cBAM  | $0.01 * \text{\_BAM}$    |
| BangladeshiTaka    | _BDT   | $0.011 * \text{\_EUR}$   |
| BangladeshiPoisha  | _cBDT  | $0.01 * \text{\_BDT}$    |
| BurundianFranc     | _BIF   | $0.00049 * \text{\_EUR}$ |
| BurundianCentime   | _cBIF  | $0.01 * \text{\_BIF}$    |
| BolivianBoliviano  | _BOB   | $0.13 * \text{\_EUR}$    |
| BolivianCentavo    | _cBOB  | $0.01 * \text{\_BOB}$    |
| BrazilianReal      | _BRL   | $0.23 * \text{\_EUR}$    |
| BrazilianCentavo   | _cBRL  | $0.01 * \text{\_BRL}$    |
| BotswanaPula       | _BWP   | $0.083 * \text{\_EUR}$   |
| BotswanaThebe      | _cBWP  | $0.01 * \text{\_BWP}$    |
| BelarusianRuble    | _BYN   | $0.42 * \text{\_EUR}$    |
| BelarusianKapiejka | _cBYN  | $0.01 * \text{\_BYN}$    |

| Name                | Symbol | Definition     |
|---------------------|--------|----------------|
| CanadianDollar      | _CAD   | 0.66 * _EUR    |
| CanadianCent        | _cCAD  | 0.01 * _CAD    |
| CongoleseFranc      | _CDF   | 0.00055 * _EUR |
| CongoleseCentime    | _cCDF  | 0.01 * _CDF    |
| SwissFranc          | _CHF   | 0.88 * _EUR    |
| SwissRappen         | _cCHF  | 0.01 * _CHF    |
| ChileanPeso         | _CLP   | 0.0013 * _EUR  |
| ChileanCentavo      | _cCLP  | 0.01 * _CLP    |
| ChineseRenminbiYuan | _CNY   | 0.13 * _EUR    |
| ChineseRenminbiFen  | _cCNY  | 0.01 * _CNY    |
| ColombianPeso       | _COP   | 0.00028 * _EUR |
| ColombianCentavo    | _cCOP  | 0.01 * _COP    |
| CostaRicanColon     | _CRC   | 0.0015 * _EUR  |
| CostaRicanCentimos  | _cCRC  | 0.01 * _CRC    |
| CzechKoruna         | _CZK   | 0.039 * _EUR   |
| CzechHaler          | _cCZK  | 0.01 * _CZK    |
| DanishKrone         | _DKK   | 0.13 * _EUR    |
| DanishOre           | _cDKK  | 0.01 * _DKK    |
| DominicanPeso       | _DOP   | 0.018 * _EUR   |
| DominicanCentavo    | _cDOP  | 0.01 * _DOP    |
| AlgerianDinar       | _DZD   | 0.0074 * _EUR  |
| AlgerianSanteem     | _cDZD  | 0.01 * _DZD    |
| EgyptianPound       | _EGP   | 0.051 * _EUR   |
| EgyptianPiastre     | _cEGP  | 0.01 * _EGP    |
| EthiopianBirr       | _ETB   | 0.031 * _EUR   |
| EthiopianSantim     | _cETB  | 0.01 * _ETB    |
| FijianDollar        | _FJD   | 0.42 * _EUR    |
| FijianCent          | _cFJD  | 0.01 * _FJD    |

| Name              | Symbol | Definition     |
|-------------------|--------|----------------|
| PoundSterling     | _GBP   | 1.16 * _EUR    |
| PennySterling     | _cGBP  | 0.01 * _GBP    |
| GeorgianLari      | _GEL   | 0.33 * _EUR    |
| GeorgianTetri     | _cGEL  | 0.01 * _GEL    |
| GhanaianCedi      | _GHS   | 0.16 * _EUR    |
| GhanaianPesewa    | _cGHS  | 0.01 * _GHS    |
| GambianDalasi     | _GMD   | 0.018 * _EUR   |
| GambianButut      | _cGMD  | 0.01 * _GMD    |
| GuineanFranc      | _GNF   | 9.6e-05 * _EUR |
| GuineanCentime    | _cGNF  | 0.01 * _GNF    |
| GuatemalanQuetzal | _GTQ   | 0.12 * _EUR    |
| GuatemalanCentavo | _cGTQ  | 0.01 * _GTQ    |
| GuyaneseDollar    | _GYD   | 0.0043 * _EUR  |
| GuyaneseCent      | _cGYD  | 0.01 * _GYD    |
| HongKongDollar    | _HKD   | 0.11 * _EUR    |
| HongKongCent      | _cHKD  | 0.01 * _HKD    |
| HonduranLempira   | _HNL   | 0.036 * _EUR   |
| HonduranCentavo   | _cHNL  | 0.01 * _HNL    |
| CroatianKuna      | _HRK   | 0.13 * _EUR    |
| CroatianLipa      | _cHRK  | 0.01 * _HRK    |
| HaitianGourde     | _HTG   | 0.011 * _EUR   |
| HaitianCentime    | _cHTG  | 0.01 * _HTG    |
| HungarianForint   | _HUF   | 0.0032 * _EUR  |
| HungarianFiller   | _cHUF  | 0.01 * _HUF    |
| IndonesianRupiah  | _IDR   | 6.2e-05 * _EUR |
| IndonesianSen     | _cIDR  | 0.01 * _IDR    |
| IsraeliNewShekel  | _ILS   | 0.25 * _EUR    |
| IsraeliNewAgora   | _cILS  | 0.01 * _ILS    |

| Name             | Symbol | Definition     |
|------------------|--------|----------------|
| IndianRupee      | _INR   | 0.013 * _EUR   |
| IndianPaissa     | _cINR  | 0.01 * _INR    |
| IraqiDinar       | _IQD   | 0.00074 * _EUR |
| IraqiFils        | _cIQD  | 0.001 * _IQD   |
| IranianRial      | _IRR   | 2.7e-05 * _EUR |
| IranianToman     | _cIRR  | 10.0 * _IRR    |
| IcelandicKrona   | _ISK   | 0.0073 * _EUR  |
| JamaicanDollar   | _JMD   | 0.007 * _EUR   |
| JamaicanCent     | _cJMD  | 0.01 * _JMD    |
| JapaneseYen      | _JPY   | 0.008 * _EUR   |
| KenyanShilling   | _KES   | 0.0089 * _EUR  |
| KenyanCent       | _cKES  | 0.01 * _KES    |
| KyrgyzstaniSom   | _KGS   | 0.013 * _EUR   |
| KyrgyzstaniTyin  | _cKGS  | 0.01 * _KGS    |
| CambodianRiel    | _KHR   | 0.00022 * _EUR |
| NorthKoreanWon   | _KPW   | 0.00099 * _EUR |
| NorthKoreanChon  | _cKPW  | 0.01 * _KPW    |
| SouthKoreanWon   | _KRW   | 0.00078 * _EUR |
| SouthKoreanJeon  | _cKRW  | 0.01 * _KRW    |
| KuwaitiDinar     | _KWD   | 2.93 * _EUR    |
| KuwaitiFils      | _cKWD  | 0.001 * _KWD   |
| KazakhstaniTenge | _KZT   | 0.0023 * _EUR  |
| KazakhstaniTiyn  | _cKZT  | 0.01 * _KZT    |
| LaoKip           | _LAK   | 0.0001 * _EUR  |
| LaoAtt           | _cLAK  | 0.01 * _LAK    |
| SriLankanRupee   | _LKR   | 0.005 * _EUR   |
| SriLankanCent    | _cLKR  | 0.01 * _LKR    |
| LiberianDollar   | _LRD   | 0.0055 * _EUR  |
| LiberianCent     | _cLRD  | 0.01 * _LRD    |

| Name                 | Symbol | Definition     |
|----------------------|--------|----------------|
| LibyanDinar          | _LYD   | 0.64 * _EUR    |
| LibyanDirham         | _cLYD  | 0.001 * _LYD   |
| MoroccanDirham       | _MAD   | 0.092 * _EUR   |
| MoroccanSantim       | _cMAD  | 0.01 * _MAD    |
| MoldovanLeu          | _MDL   | 0.052 * _EUR   |
| MoldovanBan          | _cMDL  | 0.01 * _MDL    |
| MalagasyAriary       | _MGA   | 0.00025 * _EUR |
| MalagasyIraimbilanja | _cMGA  | 0.2 * _MGA     |
| MacedonianDenar      | _MKD   | 0.016 * _EUR   |
| MacedonianDeni       | _cMKD  | 0.01 * _MKD    |
| BurmeseKyat          | _MMK   | 0.00059 * _EUR |
| BurmesePya           | _cMMK  | 0.01 * _MMK    |
| MongolianTogrog      | _MNT   | 0.00034 * _EUR |
| MongolianMongol      | _cMNT  | 0.01 * _MNT    |
| MauritanianOuguiya   | _MRU   | 0.025 * _EUR   |
| MauritanianKhoudms   | _cMRU  | 0.2 * _MRU     |
| MauritianRupee       | _MUR   | 0.025 * _EUR   |
| MauritianCent        | _cMUR  | 0.01 * _MUR    |
| MaldivianRufiyaa     | _MVR   | 0.058 * _EUR   |
| MaldivianLaari       | _cMVR  | 0.01 * _MVR    |
| MalawianKwacha       | _MWK   | 0.0012 * _EUR  |
| MalawianTambala      | _cMWK  | 0.01 * _MWK    |
| MexicanPeso          | _MXN   | 0.046 * _EUR   |
| MexicanCentavo       | _cMXN  | 0.01 * _MXN    |
| MalaysianRinggit     | _MYR   | 0.22 * _EUR    |
| MalaysianSen         | _cMYR  | 0.01 * _MYR    |
| MozambicanMetical    | _MZN   | 0.014 * _EUR   |
| MozambicanCentavo    | _cMZN  | 0.01 * _MZN    |

| Name                | Symbol | Definition     |
|---------------------|--------|----------------|
| NigerianNaira       | _NGN   | 0.0025 * _EUR  |
| NigerianKobo        | _cNGN  | 0.01 * _NGN    |
| NicaraguanCordoba   | _NIO   | 0.027 * _EUR   |
| NicaraguanCentavo   | _cNIO  | 0.01 * _NIO    |
| NorwegianKrone      | _NOK   | 0.1 * _EUR     |
| NorwegianOre        | _cNOK  | 0.01 * _NOK    |
| NewZealandDollar    | _NZD   | 0.61 * _EUR    |
| NewZealandCent      | _cNZD  | 0.01 * _NZD    |
| PeruvianSol         | _PEN   | 0.27 * _EUR    |
| PeruvianCentimo     | _cPEN  | 0.01 * _PEN    |
| PapuaNewGuineanKina | _PGK   | 0.26 * _EUR    |
| PapuaNewGuineanToea | _cPGK  | 0.01 * _PGK    |
| PhilippinePeso      | _PHP   | 0.017 * _EUR   |
| PhilippineSentimo   | _cPHP  | 0.01 * _PHP    |
| PakistaniRupee      | _PKR   | 0.0064 * _EUR  |
| PakistaniPaissa     | _cPKR  | 0.01 * _PKR    |
| PolishZloty         | _PLN   | 0.23 * _EUR    |
| PolishGrosz         | _cPLN  | 0.01 * _PLN    |
| ParaguayanGuarani   | _PYG   | 0.00015 * _EUR |
| ParaguayanCentimo   | _cPYG  | 0.01 * _PYG    |
| QatariRiyal         | _QAR   | 0.24 * _EUR    |
| QatariDirham        | _cQAR  | 0.01 * _QAR    |
| RomanianLeu         | _RON   | 0.21 * _EUR    |
| RomanianBan         | _cRON  | 0.01 * _RON    |
| SerbianDinar        | _RSD   | 0.0085 * _EUR  |
| SerbianPara         | _cRSD  | 0.01 * _RSD    |
| RussianRuble        | _RUB   | 0.013 * _EUR   |
| RussianKopeyka      | _cRUB  | 0.01 * _RUB    |

| Name                 | Symbol | Definition     |
|----------------------|--------|----------------|
| RwandanFranc         | _RWF   | 0.00098 * _EUR |
| RwandanCentime       | _cRWF  | 0.01 * _RWF    |
| SolomonIslandsDollar | _SBD   | 0.11 * _EUR    |
| SolomonIslandsCent   | _cSBD  | 0.01 * _SBD    |
| SeychelloisRuppee    | _SCR   | 0.065 * _EUR   |
| SeychelloisCent      | _cSCR  | 0.01 * _SCR    |
| SudanesePound        | _SDG   | 0.019 * _EUR   |
| SudaneseQirsh        | _cSDG  | 0.01 * _SDG    |
| SwedishKrona         | _SEK   | 0.094 * _EUR   |
| SwedishOre           | _cSEK  | 0.01 * _SEK    |
| SingaporeDollar      | _SGD   | 0.65 * _EUR    |
| SingaporeCent        | _cSGD  | 0.01 * _SGD    |
| SierraLeoneanLeone   | _SLL   | 0.0001 * _EUR  |
| SierraLeoneanCent    | _cSLL  | 0.01 * _SLL    |
| SomalilandShilling   | _SQS   | 0.00013 * _EUR |
| SomalilandCent       | _cSQS  | 0.01 * _SQS    |
| SomaliShilling       | _SOS   | 0.0015 * _EUR  |
| SomaliSenti          | _cSOS  | 0.01 * _SOS    |
| SurinameseDollar     | _SRD   | 0.12 * _EUR    |
| SurinameseCent       | _cSRD  | 0.01 * _SRD    |
| SyrianPound          | _SYP   | 0.0017 * _EUR  |
| SyrianPiastre        | _cSYP  | 0.01 * _SYP    |
| ThaiBaht             | _THB   | 0.028 * _EUR   |
| ThaiSatang           | _cTHB  | 0.01 * _THB    |
| TajikistaniSamani    | _TJS   | 0.094 * _EUR   |
| TajikistaniDiram     | _cTJS  | 0.01 * _TJS    |
| Tonganpaanga         | _TOP   | 0.397 * _EUR   |
| TonganSeniti         | _cTOP  | 0.01 * _TOP    |

| Name                      | Symbol | Definition     |
|---------------------------|--------|----------------|
| TurkishLira               | _TRY   | 0.16 * _EUR    |
| TurkishKurus              | _cTRY  | 0.01 * _TRY    |
| TrinidadAndTobagoDollar   | _TTD   | 0.13 * _EUR    |
| TrinidadAndTobagoCent     | _cTTD  | 0.01 * _TTD    |
| NewTaiwanDollar           | _TWD   | 0.029 * _EUR   |
| NewTaiwanCent             | _cTWD  | 0.01 * _TWD    |
| TanzanianShilling         | _TZS   | 0.00038 * _EUR |
| TanzanianSenti            | _cTZS  | 0.01 * _TZS    |
| UkrainianHryvnia          | _UAH   | 0.00038 * _EUR |
| UkrainianKopiyka          | _cUAH  | 0.01 * _UAH    |
| UgandanShilling           | _UGX   | 0.00024 * _EUR |
| UgandanCent               | _cUGX  | 0.01 * _UGX    |
| USDollar                  | _USD   | 0.89 * _EUR    |
| USCent                    | _cUSD  | 0.01 * _USD    |
| UruguayanPeso             | _UYU   | 0.027 * _EUR   |
| UruguayanCentesimo        | _cUYU  | 0.01 * _UYU    |
| UzbekistaniSom            | _UZS   | 0.00011 * _EUR |
| UzbekistaniTiyin          | _cUZS  | 0.01 * _UZS    |
| VenezuelanBolivarSoberano | _VES   | 0.0003 * _EUR  |
| VenezuelanCentimoSoberano | _cVES  | 0.01 * _VES    |
| VietnameseDong            | _VND   | 3.8e-05 * _EUR |
| VietnameseXu              | _cVND  | 0.01 * _VND    |
| SamoaTala                 | _WST   | 0.34 * _EUR    |
| SamoaSene                 | _cWST  | 0.01 * _WST    |
| YemeniRial                | _YER   | 0.0036 * _EUR  |
| YemeniDinar               | _cYER  | 0.01 * _YER    |
| SouthAfricanRand          | _ZAR   | 0.062 * _EUR   |
| SouthAfricanCent          | _cZAR  | 0.01 * _ZAR    |
| ZambianKwacha             | _ZMW   | 0.074 * _EUR   |
| ZambianNgwee              | _cZMW  | 0.01 * _ZMW    |



#### 4.10.1 Pegged International Currencies

International currency which are pegged to other currencies.

| Name                        | Symbol | Definition           |
|-----------------------------|--------|----------------------|
| UnitedArabEmiratesDirham    | _AED   | $(1/3.6725) * \_USD$ |
| UnitedArabEmiratesFils      | _cAED  | $0.01 * \_AED$       |
| NetherlandsAntilleanGuilder | _ANG   | $(1/1.79) * \_USD$   |
| NetherlandsAntilleanCent    | _cANG  | $0.01 * \_ANG$       |
| ArubanFlorin                | _AWG   | $(1/1.79) * \_USD$   |
| ArubanCent                  | _cAWG  | $0.01 * \_AWG$       |
| BarbadianDollar             | _BBD   | $0.5 * \_USD$        |
| BarbadianCent               | _cBBD  | $0.01 * \_BBD$       |
| BulgarianLev                | _BGN   | $0.51129 * \_EUR$    |
| BulgarianStotinka           | _cBGN  | $0.01 * \_BGN$       |
| BahrainiDinar               | _BHD   | $(1/0.376) * \_USD$  |
| BahrainiFils                | _cBHD  | $0.001 * \_BHD$      |
| BermudianDollar             | _BMD   | $1 * \_USD$          |
| BermudianCent               | _cBMD  | $0.01 * \_BMD$       |
| BruneiDollar                | _BND   | $1 * \_SGD$          |
| BruneiSen                   | _cBND  | $0.01 * \_BND$       |
| BahamianDollar              | _BSD   | $1 * \_USD$          |
| BahamianCent                | _cBSD  | $0.01 * \_BSD$       |
| BhutaneseNgultrum           | _BTN   | $1 * \_INR$          |
| BhutaneseChhertum           | _cBTN  | $0.01 * \_BTN$       |
| BelizeDollar                | _BZD   | $0.5 * \_USD$        |
| BelizeCent                  | _cBZD  | $0.01 * \_BZD$       |
| CubanoConvertiblePeso       | _CUC   | $1 * \_USD$          |
| CubanoConvertibleCentavo    | _cCUC  | $0.01 * \_CUC$       |
| CubanPeso                   | _CUP   | $(1/24) * \_CUC$     |
| CubanCentavo                | _cCUP  | $0.01 * \_CUP$       |

| Name                 | Symbol | Definition                     |
|----------------------|--------|--------------------------------|
| CapeVerdeanEscudo    | _CVE   | $(1/110.265) * \text{\_EUR}$   |
| CapeVerdeanCentavo   | _cCVE  | $0.01 * \text{\_CVE}$          |
| DjiboutianFranc      | _DJF   | $(1/177.721) * \text{\_USD}$   |
| DjiboutianCentime    | _cDJF  | $0.01 * \text{\_DJF}$          |
| EritreanNakfa        | _ERN   | $(1/15) * \text{\_USD}$        |
| EritreanCent         | _cERN  | $0.01 * \text{\_ERN}$          |
| FalklandIslandsPound | _FKP   | $1 * \text{\_GBP}$             |
| FalklandIslandsPenny | _cFKP  | $0.01 * \text{\_FKP}$          |
| GuernseyPound        | _GGP   | $1 * \text{\_GBP}$             |
| GuernseyPenny        | _cGGP  | $0.01 * \text{\_GGP}$          |
| GibraltarPound       | _GIP   | $1 * \text{\_GBP}$             |
| GibraltarPenny       | _cGIP  | $0.01 * \text{\_GIP}$          |
| ManxPound            | _IMP   | $1 * \text{\_GBP}$             |
| ManxPenny            | _cIMP  | $0.01 * \text{\_IMP}$          |
| JerseyPound          | _JEP   | $1 * \text{\_GBP}$             |
| JerseyPenny          | _cJEP  | $0.01 * \text{\_JEP}$          |
| JordanianDinar       | _JOD   | $(1/0.708) * \text{\_USD}$     |
| JordanianFils        | _cJOD  | $0.001 * \text{\_JOD}$         |
| KiribatiDollar       | _KID   | $1 * \text{\_AUD}$             |
| KiribatiCent         | _cKID  | $0.01 * \text{\_KID}$          |
| Comorianfranc        | _KMF   | $(1/491.96775) * \text{\_EUR}$ |
| ComorianCentime      | _cKMF  | $0.01 * \text{\_KMF}$          |
| CaymanIslandsDollar  | _KYD   | $1.2 * \text{\_USD}$           |
| CaymanIslandsCent    | _cKYD  | $0.01 * \text{\_KYD}$          |
| LebanesePound        | _LBP   | $(1/1507.5) * \text{\_USD}$    |
| LebaneseQeresh       | _cLBP  | $0.01 * \text{\_LBP}$          |
| MacanesePataca       | _MOP   | $(1/1.03) * \text{\_HKD}$      |
| MacaneseAvo          | _cMOP  | $0.01 * \text{\_MOP}$          |

| Name                      | Symbol | Definition         |
|---------------------------|--------|--------------------|
| NamibianDollar            | _NAD   | 1 * _ZAR           |
| NamibianCent              | _cNAD  | 0.01 * _NAD        |
| NepaleseRupee             | _NPR   | (1/1.6) * _INR     |
| NepalesePaissa            | _cNPR  | 0.01 * _NPR        |
| OmaniRial                 | _OMR   | (1/2.6008) * _USD  |
| OmaniBaisa                | _cOMR  | 0.001 * _OMR       |
| PanamanianBalboa          | _PAB   | 1 * _USD           |
| PanamanianCentesimo       | _cPAB  | 0.01 * _PAB        |
| TransnistrianRuble        | _PRB   | (1/16.1) * _USD    |
| TransnistrianKopeck       | _cPRB  | 0.01 * _PRB        |
| SaudiRiyal                | _SAR   | (1/3.75) * _USD    |
| SaudiHalalah              | _cSAR  | 0.01 * _SAR        |
| SaintHelenaPound          | _SHP   | 1 * _GBP           |
| SaintHelenaPenny          | _cSHP  | 0.01 * _SHP        |
| SouthSudanesePound        | _SSP   | 1 * _SDG           |
| SouthSudanesePiaster      | _cSSP  | 0.01 * _SSP        |
| SaoTomeAndPrincipeDobra   | _STN   | (1/24.5) * _EUR    |
| SaoTomeAndPrincipeCentimo | _cSTN  | 0.01 * _STN        |
| SwaziLilangeni            | _SZL   | 1 * _ZAR           |
| SwaziCent                 | _cSZL  | 0.01 * _SZL        |
| TurkmenistanManat         | _TMT   | (1/3.5) * _USD     |
| TurkmenistanTenge         | _cTMT  | 0.01 * _TMT        |
| TuvaluanDollar            | _TVD   | 1 * _AUD           |
| TuvaluanCent              | _cTVD  | 0.01 * _TVD        |
| CentralAfricanCFAFranc    | _XAF   | (1/655.957) * _EUR |
| CentralAfricanCFACentime  | _cXAF  | 0.01 * _XAF        |
| EasternCaribbeanDollar    | _XCD   | (1/2.7) * _USD     |
| EasternCaribbeanCent      | _cXCD  | 0.01 * _XCD        |

| Name                  | Symbol | Definition                   |
|-----------------------|--------|------------------------------|
| WestAfricanCFAFranc   | _XOF   | $(1/655.957) * \text{\_USD}$ |
| WestAfricanCFACentime | _cXOF  | $0.01 * \text{\_XOF}$        |
| CFPFranc              | _XPF   | $(1000/8.38) * \text{\_EUR}$ |
| CFPCentime            | _cXPF  | $0.01 * \text{\_XPF}$        |
| ZimbabweanBonds       | _ZWL   | $1 * \text{\_USD}$           |
| ZimbabweanCent        | _cZWL  | $0.01 * \text{\_ZWL}$        |

## 5 Lua Documentation

In this section, the following shortcuts will be used.

```
local D = physical.Dimension
local U = physical.Unit
local N = physical.Number
local Q = physical.Quantity
```

The term **number** refers to a lua integer or a lua float number. By **string** a lua string is meant and by **bool** a lua boolean.

### 5.1 physical.Quantity

The quantity class is the main part of the library. Each physical Quantity and all units are represented by an instance of this class.

#### **Q.new(q=nil)**

Copy Constuctor

**q** : Q, number, object, nil

returns : Q

As an argument it takes Q, **number**, **object** or **nil**. If an instance of Q is given, a copy is made and returned. If a **number** or an instance **object** of another class is given, the function creates a dimensionless quantity with the **number** or the instance as a value. In the case **nil** is given, a dimensionless quantity with value 1 is returned.

```
print( Q() )
1

print( Q(42) )
42

print( Q(73*_m) )
73 * _m
```

#### **Q.defineBase(symbol,name,dimension)**

This function is used to declare base quantities from which all other quantities are derived from.

**symbol** : string

The symbol of the base quantity.

**name** : string  
The name of the base quantity.

**dimension** : D  
An instance of the D class, which represents the dimension of the quantity.

returns : Q  
The created Q instance.

The function creates a global variable of the created base quantity. The name consist of an underscore concatenated with the **symbol** argument, i.e. the symbol **m** becomes the global variable **\_m**.

The **name** is used for example in the siunitx conversion function, e.g **meter** will be converted to **\meter**.

Each quantity has a dimension associated with it. The argument **dimension** allows any dimension to be associated to base quantities.

```
Q.defineBase("m", "meter", L)
Q.defineBase("kg", "kilogram", M)
```

## **Q.define(symbol, name, q)**

Creates a new derived quantity from an expression of other quantities. Affine quantities like the absolute temperature in celsius are not supported.

**symbol** : string  
Symbol of the base quantity

**name** : string, nil  
The Name of the derived quantity.

**q** : physical.Quantity  
The definition of the derived quantity.

returns : Q  
The created quantity.

The function creates a global variable of the created base quantity. The name consist of an underscore concatenated with the **symbol** argument, i.e. the symbol **N** becomes the global variable **\_N**.

The **name** is used for example in the siunitx conversion function, e.g **newton** will be converted to **\newton**.

```
Q.define("L", "liter", _dm^3)
Q.define("Pa", "pascal", _N/_m^2)
Q.define("C", "coulomb", _A*_s)

Q.define("degC", "celsius", _K)
```

### **Q.definePrefix(symbol,name,factor)**

Defines a new prefix.

**symbol** : string  
Symbol of the base quantity  
**name** : string  
Name of the base quantity  
**factor** : number  
The factor which corresponds to the prefix

```
Q.definePrefix("c", "centi", 1e-2)
Q.definePrefix("a", "atto", 1e-18)
```

### **Q.addPrefix(prefixes, units)**

Create several units with prefixes from a given unit.

**prefixes** : string  
A list of unit symbols.  
**units** : Q  
A list of quantities.

```
Q.addPrefix({"n","u","m","k","M","G"},{_m,_s,_A})
```

### **Q.isclose(self,q,r)**

Checks if this quantity is close to another one. The argument **r** is the maximum relative deviation. The function returns **true** if the following condition is fulfilled

$$\frac{abs(self - q)}{min(self,q)} \leq r \quad .$$

**self** : Q, N, number  
**q** : Q, N, number  
**r** : number  
maximum relative deviation of **self** and **q**  
returns : bool  
true if **q** is close to **self**, otherwise false

```

s_1 = 1.9 * _m
s_2 = 2.0 * _m
print( s_1:isclose(s_2,0.1) )
true
print( s_1:isclose(s_2,0.01) )
false

```

### **Q.to(self,q=nil)**

Converts the quantity **self** to the unit of the quantity **q**. If no **q** is given, the quantity **self** is converted to base units.

```

self : Q
q : Q, nil

```

```

s = 1.9 * _km
print( s:to(_m) )
1900.0 * _m

T = 10 * _degC
print( T:to(_K) )
10.0 * _K

print( T:to() )
10 * _K

```

### **Q.tosiunitx(self,param,mode=Q.siunitx\_SI)**

Converts the quantity into a **siunitx** string.

```

self : Q
param : string
mode : number

```

If **mode** is equal **Q.SIUNITX\_SI**, which is the default, the quantity is converted to an `\SI{...}{...}` macro. If **mode** is **Q.SIUNITX\_num**, the quantity is converted to `\num{...}` and if it is **Q.SIUNITX\_si** the macro `\si{...}` is printed.

```

s = 1.9 * _km

print( s:tosiunitx() )
\SI{1.9}{\kilo\meter}

print( s:tosiunitx(nil,Q.SIUNITX_num) )
\num{1.9}

print( s:tosiunitx(nil,Q.SIUNITX_si) )
\si{\kilo\meter}

```



### **Q.min(q1, q2, ...)**

Returns the smallest quantity of the given ones. The function returns q1 if the Quantities are equal.

q1 : Q, N, number

q2 : Q, N, number

...

qN : Q, N, number

returns : Q

the smallest quantity of q1, ... , qN

```
s_1 = 15 * _m
s_2 = 5 * _m
print(s_1:min(s_2))
5 * _m
```

### **Q.max(q1, q2, ...)**

Returns the biggest quantity of several given ones. The function returns q1 if the Quantities are equal.

q1 : Q, N, number

q2 : Q, N, number

...

qN : Q, N, number

returns : Q

the biggest quantity of q1, ... , qN

```
s_1 = 15 * _m
s_2 = 5 * _m
print(s_1:max(s_2))
15 * _m
```

### **Q.abs(q)**

Returns the absolute value of the given quantity q.

q : Q, N, number

returns : Q

the absolute value of q

```

U = -5 * _V
print(U)
-5 * _V
print(U:abs())
5 * _V

```

### **Q.sqrt(q)**

Returns the square root of the given quantity.

**q** : Q, N, number  
dimensionless argument

returns : Q  
the square root of **q**

```

A = 25 * _m^2
s = A:sqrt()
print(s)
5.0 * _m

```

### **Q.log(q, base=nil)**

Returns the logarithm of a given quantity to the given base. If no base is given, the natural logarithm is returned.

**q** : Q, N, number  
dimensionless argument

**base** : Q, N, number, nil  
dimensionless argument

returns : Q  
logarithm of **q** to the **base**

```

I = 1 * _W/_m^2
I_0 = 1e-12 * _W/_m^2
print(10 * (I/I_0):log(10) * _dB )
120.0 * _dB

```

### **Q.exp(q)**

Returns the value of the natural exponential function of the given quantity.

**q** : Q, N, number  
dimensionless argument

returns : Q  
natural exponential of q

```
x = 2 * _1
print( x:exp() )
7.3890560989307
```

### **Q.sin(q)**

Returns the value of the sinus function of the given quantity.

q : Q, N, number  
dimensionless argument  
returns : Q  
sine of q

```
alpha = 30 * _deg
print( alpha:sin() )
0.5
```

### **Q.cos(q)**

Returns the value of the cosinus function of the given quantity. The quantity has to be dimensionless.

q : Q, N, number  
dimensionless argument  
returns : Q  
cosine of q

```
alpha = 60 * _deg
print( alpha:cos() )
0.5
```

### **Q.tan(q)**

Returns the value of the tangent function of the given quantity. The quantity has to be dimensionless.

q : Q, N, number  
dimensionless argument  
returns : Q  
tangent of q

```
alpha = 45 * _deg
print( alpha:tan() )
1.0
```

### **Q.asin(q)**

Returns the value of the arcus sinus function of the given quantity.  
The quantity has to be dimensionless.

**q** : Q, N, number  
dimensionless argument  
**returns** : Q  
inverse sine of **q**

```
x = 0.5 * _1
print( x:asin():to(_deg) )
30.0 * _deg
```

### **Q.acos(q)**

Returns the value of the arcus cosinus function of the given quantity.  
The quantity has to be dimensionless.

**q** : Q, N, number  
dimensionless argument  
**returns** : Q  
inverse cosine of **q**

```
x = 0.5 * _1
print( x:acos():to(_deg) )
60.0 * _deg
```

### **Q.atan(q)**

Returns the value of the arcus tangent function of the given quantity.  
The quantity has to be dimensionless.

**q** : Q, N, number  
dimensionless argument  
**returns** : Q  
inverse tangent of **q**

```
x = 1 * _1
print( x:atan():to(_deg) )
45.0 * _deg
```

### **Q.sinh(q)**

Returns the value of the hyperbolic sine function of the given quantity. The quantity has to be dimensionless. Since Lua doesn't implement the hyperbolic functions, the following formula is used

$$\sinh(x) = 0.5 \cdot e^x - 0.5/e^x \quad .$$

**q** : Q, N, number  
dimensionless argument  
returns : Q  
hyperbolic sine of q

```
x = 1 * _1
print( x:sinh() )
1.1752011936438
```

### **Q.cosh(q)**

Returns the value of the hyperbolic cosine function of the given quantity. The quantity has to be dimensionless. Since Lua doesn't implement the hyperbolic functions, the following formula is used

$$\cosh(x) = 0.5 \cdot e^x + 0.5/e^x \quad .$$

**q** : Q, N, number  
dimensionless argument  
returns : Q  
hyperbolic cosine of q

```
x = 1 * _1
print( x:cosh() )
1.5430806348152
```

### **Q.tanh(q)**

Returns the value of the hyperbolic tangent function of the given quantity. The quantity has to be dimensionless. Since Lua doesn't implement the hyperbolic functions, the following formula is used

$$\tanh(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} \quad .$$

**q** : Q, N, number  
dimensionless argument  
returns : Q  
hyperbolic tangent of q

```
x = 1 * _1
print( x:tanh() )
0.76159415595576
```

### Q.asinh(q)

Returns the value of the inverse hyperbolic sine function of the given quantity. The quantity has to be dimensionless. Since Lua doesn't implement the hyperbolic functions, the following formula is used

$$\operatorname{asinh}(x) = \ln \left( x + \sqrt{x^2 + 1} \right) \quad .$$

q : Q, N, number  
dimensionless argument  
returns : Q  
inverse hyperbolic sine of q

```
x = 1 * _1
print( x:asinh() )
0.88137358701954
```

### Q.acosh(q)

Returns the value of the inverse hyperbolic cosine function of the given quantity. The quantity has to be dimensionless. Since Lua doesn't implement the hyperbolic functions, the following formula is used

$$\operatorname{acosh}(x) = \ln \left( x + \sqrt{x^2 - 1} \right) \quad , x > 1 \quad .$$

q : Q, N, number  
dimensionless argument bigger or equal to one  
returns : Q  
inverse hyperbolic cosine of q

```
x = 2 * _1
print( x:acosh() )
1.3169578969248
```

### Q.atanh(q)

Returns the value of the inverse hyperbolic tangent function of the given quantity. The quantity has to be dimensionless. Since Lua doesn't implement the hyperbolic functions, the following formula is used

$$\operatorname{atanh}(x) = \ln \left( \frac{1+x}{1-x} \right) \quad , -1 < x < 1 \quad .$$

**q** : Q, N, number  
dimensionless argument with magnitude smaller than one  
**returns** : Q  
inverse hyperbolic tangent of **q**

```
x = 0.5 * _1
print( x:atanh() )
0.54930614433405
```

## 5.2 physical.Dimension

All physical quantities do have a physical dimension. For example the quantity *Area* has the dimension  $L^2$  (length to the power of two). In the SI-System there are seven base dimensions, from which all other dimensions are derived. Each dimension is represented by an  $n$ -tuple, where  $n$  is the number of base dimensions. Each physical quantity has an associated dimension object. It is used to check equality and if addition or subtraction is allowed.

### D.new(d)

Constructor of the **Dimension** class.

**d** : **Dimension** or **string**, **nil**  
The name or symbol of the dimension.  
**returns** : **D**  
The created **D** instance

If **d** is a string, a copy of the perviously defined dimension is made.  
If **d** is a dimension, a copy of it is made. If no argument ist given, a dimension *zero* is created.

### Example

```
V_1 = D("Velocity")
L = D("L")
V_2 = D(L/T)
```

### D.defineBase(symbol, name)

Defines a base dimension.

**symbol** : **string**  
  
**name** : **string**  
  
**returns** : **D**  
The created **D** instance

### Example

```
V_1 = D("Velocity")
L = D("L")
V_2 = D(L/T)
```



### 5.3 physical.Unit

The task of this class is keeping track of the unit term. The unit term is a fraction of units. The units in the enumerator and denominator can have an exponent.

#### **Unit.new(u=nil)**

Copy Constructor. It copies a given unit object. If nothing is given, an empty unit is created.

**u : Unit**  
The unit object which will be copied.  
**returns : Unit**  
The created **Unit** object

#### **Unit.new(symbol, name, prefixsymbol=nil, prefixname=nil)**

Constructor. A new **Unit** object with symbol is created. The prefixsymbol and prefixname are optional.

**symbol : String**  
The symbol of the unit.  
**name : String**  
The name of the unit.  
**prefixsymbol : String**  
The optional symbol of the prefix.  
**prefixname : String**  
The optional name of the prefix.  
**returns : Unit**  
The created **Unit** object

#### **Unit.tosiunitx(self)**

The unit term will be compiled into a string, which the LaTeX package siunitx can understand.

**returns : String**  
The siunitx representation of the unit term.

## 5.4 physical.Number

This class enhances the Lua number with an uncertainty and gaussian error propagation. A number instance has a mean value called **x** and an uncertainty value called **dx**.

### **N.omitUncertainty=true**

This variable controls, whether the uncertainty **dx** is printed or not. The default value is **true**, i.e. the uncertainty is omitted.

```
n = N(45,0.012)

N.omitUncertainty = false
print(n)
(45.000 +/- 0.012)

N.omitUncertainty = true
print(n)
45.0
```

### **N.seperateUncertainty=true**

This variable controls, how the uncertainty is printed. If set to **false**, the parenthesis notation is used. If set to **true** the plus minus notation is used. The default value is **true**.

```
n = N(56,0.025)

N.seperateUncertainty = false
print(n)
56.00(3)

N.seperateUncertainty = true
print(n)
(56.00 +/- 0.03)
```

### **N.format=N.Scientific**

This variable controls, how the number is printed. If set to **N.Scientific**, scientific notation is used. If set to **N.DECIMAL** the decimal notation is used. The default value is **N.Scientific**.

```
n = N(12000000,0.1)

N.format = N.Scientific
print(n)
1.2000000e7
```

```
N.format = N.DECIMAL
print(n)
12000000
```

### **N.new(n=nil)**

This is the copy Constructor for the **Number** class. It copies a given number object. If **n** is **nil**, an instance representing number zero with uncertainty zero is created.

**n** : **Number**  
The number object to be copied.

returns : **Number**  
The created **Number** instance.

```
n = N(56,0.012)
m = N(n)
print(m)
56.0
```

### **N.new(x, dx=nil)**

This constructor, creates a new instance of **N** with mean value **x** and uncertainty **dx**. If **dx** is not given, the uncertainty is zero.

**x** : **number**  
mean value

**dx** : **number, nil**  
uncertainty value

returns : **N**  
The created **N** instance.

```
n = N(56,0.012)
print(n)
56.0
```

### **N.new(str)**

This constructor creates a new instance of **N** from a string. It can parse strings of the form "3.4", "3.4e-3", "5.4e-3 +/- 2.4e-6" and "5.45(7)e-23".

**str** : **string**

returns : N

```
n_1 = N("12.3e-3")
print(n_1)
0.0123

n_2 = N("12 +/- 0.1")
print(n_2)
12

n_3 = N("12.0(1)")
print(n_3)
12

n_4 = N("15.0(12)")
print(n_4)
15.0
```

### **N.mean(n)**

Returns the mean value of **n**.

#### **Parameters / Return**

returns : number

```
n = N(1.25,0.0023)
print( n:mean() )
1.25
```

### **N.uncertainty(n)**

Returns the uncertainty value of **n**.

**n** : N

returns : number

```
n = N(1.25,0.0023)
print( n:uncertainty() )
0.0023
```

### **N.abs(n)**

Returns the absolute value of **n**.

**n** : N

returns : N

The uncertainty  $\Delta y$  is calculated by the following expression

$$\Delta y = \Delta x \quad .$$

```
n = N(-10,1)
print( n:abs() )
10.0
```

### **N.sqrt(n)**

Returns the square root of **n**.

**n** : N  
returns : N

The uncertainty  $\Delta y$  is calculated by the following expression

$$\Delta y = \frac{1}{2\sqrt{x}} \cdot \Delta x \quad .$$

```
n = N(25,1)
print( n:sqrt() )
5
```

### **N.log(n,base=nil)**

Returns the logarithm of a given number **n** to the given base **base**. If no base is given, the natural logarithm of **n** is returned.

**n** : N  
**base** : number, nil  
returns : N

The uncertainty  $\Delta y$  is calculated by the following expression

$$\Delta y = \frac{1}{|x \cdot \log(b)|} \cdot \Delta x \quad .$$

```
n = N(25,1)
print( n:log() )
3.2
```

### **N.exp(n)**

Returns the value of the natural exponential function of the given number.

**q** : N  
returns : N

The uncertainty  $\Delta y$  is calculated by the following expression

$$\Delta y = e^x \cdot \Delta x \quad .$$

```
n = N(25,1)
print( n:sqrt() )
5
```

### **N.sin(n)**

Returns the value of the sine function of the given number.

**n** : N  
returns : N

The uncertainty  $\Delta y$  is calculated by the following expression

$$\Delta y = | \cos(x) | \cdot \Delta x \quad .$$

```
n = N(3,0.1)
print( n:sin() )
0.1
```

### **N.cos(n)**

Returns the value of the cosine function of the given number.

**n** : N  
returns : N

The uncertainty  $\Delta y$  is calculated by the following expression

$$\Delta y = | \sin(x) | \cdot \Delta x \quad .$$

```
n = N(0.5,0.01)
print( n:cos() )
0.88
```

### **N.tan(n)**

Returns the value of the tangent function of the given number.

**n** : N

returns : N

The uncertainty  $\Delta y$  is calculated by the following expression

$$\Delta y = \left| \frac{1}{\cos^2(x)} \right| \cdot \Delta x \quad .$$

```
n = N(1.5,0.001)
print( n:tan() )
14
```

### **N.asin(n)**

Returns the value of the inverse sine function of the given number.

**n** : N

returns : N

The uncertainty  $\Delta y$  is calculated by the following expression

$$\Delta y = \frac{1}{\sqrt{1-x^2}} \cdot \Delta x \quad .$$

```
n = N(0.99,0.001)
print( n:asin() )
1.43
```

### **N.acos(n)**

Returns the value of the inverse cosine function of the given number.

**n** : N

returns : N

The uncertainty  $\Delta y$  is calculated by the following expression

$$\Delta y = \frac{1}{\sqrt{1-x^2}} \cdot \Delta x \quad .$$

```
n = N(0.99,0.001)
print( n:acos() )
0.14
```

### **N.atan(n)**

Returns the value of the inverse tangent function of the given number.

**n** : N

returns : N

The uncertainty  $\Delta y$  is calculated by the following expression

$$\Delta y = \frac{1}{\sqrt{1+x^2}} \cdot \Delta x \quad .$$

```
n = N(1,0.001)
print( n:atan() )
0.785
```

### **N.sinh(q)**

Returns the value of the hyperbolic sine function of the given number.

**n** : N

returns : N

Since Lua doesn't implement the hyperbolic functions, the following formula is used

$$\sinh(x) = 0.5 \cdot e^x - 0.5/e^x \quad .$$

The uncertainty  $\Delta y$  is calculated by the following expression

$$\Delta y = (0.5 \cdot e^x + 0.5/e^x) \cdot \Delta x \quad .$$

```
n = N(1,0.001)
print( n:sinh() )
1.18
```

### **N.cosh(q)**

Returns the value of the hyperbolic cosine function of the given number.

**n** : N

returns : N



Since Lua doesn't implement the hyperbolic functions, the following formula is used

$$\cosh(x) = 0.5 \cdot e^x + 0.5/e^x \quad .$$

The uncertainty  $\Delta y$  is calculated by the following expression

$$\Delta y = (0.5 \cdot e^x - 0.5/e^x) \cdot \Delta x \quad .$$

```
n = N(1,0.001)
print( n:cosh() )
1.54
```

### **N.tanh(q)**

Returns the value of the hyperbolic tangent function of the given number.

**n** : N

returns : N

Since Lua doesn't implement the hyperbolic functions, the following formula is used

$$\tanh(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} \quad .$$

The uncertainty  $\Delta y$  is calculated by the following expression

$$\Delta y = \frac{1}{(0.5 \cdot e^x + 0.5/e^x)^2} \cdot \Delta x \quad .$$

```
n = N(1,0.001)
print( n:tanh() )
0.762
```

### **Q.asinh(q)**

Returns the value of the inverse hyperbolic sine function of the given number.

**n** : N

returns : N

Since Lua doesn't implement the hyperbolic functions, the following formula is used

$$\operatorname{asinh}(x) = \ln \left( x + \sqrt{x^2 + 1} \right) \quad .$$

The uncertainty  $\Delta y$  is calculated by the following expression

$$\Delta y = \frac{1}{\sqrt{x^2 + 1}} \cdot \Delta x \quad .$$

```
n = N(1,0.001)
print( n:asinh() )
0.881
```

### Q.acosh(q)

Returns the value of the inverse hyperbolic cosine function of the given number.

**n** : N  
returns : N

Since Lua doesn't implement the hyperbolic functions, the following formula is used

$$\operatorname{acosh}(x) = \ln \left( x + \sqrt{x^2 - 1} \right) \quad , x > 1 \quad .$$

The uncertainty  $\Delta y$  is calculated by the following expression

$$\Delta y = \frac{1}{\sqrt{x^2 - 1}} \cdot \Delta x \quad .$$

```
n = N(2,0.001)
print( n:acosh() )
1.317
```

### Q.atanh(q)

Returns the value of the inverse hyperbolic tangent function of the given number.

**n** : N  
returns : N

Since Lua doesn't implement the hyperbolic functions, the following formula is used

$$\operatorname{atanh}(x) = \ln\left(\frac{1+x}{1-x}\right) \quad , -1 < x < 1 \quad .$$

The uncertainty  $\Delta y$  is calculated by the following expression

$$\Delta y = \frac{1}{|x^2 - 1|} \cdot \Delta x \quad .$$

```
n = N(-0.5,0.0001)
print( n:atanh() )
-0.549
```

## 6 Change History

V1.0.4 (2020/09/15) **Minor release**

Changed default value of `Number.omitUncertainty` and `Number.seperateUncertainty` to `true`. Documentation added.

V1.0.3 (2020/09/09) **Minor release**

Changed foldername `physical` to `src`. Changed Classvariables `Q.siunitx_SI`, `Q.siunitx_num` and `Q.siunitx_si` to uppercase `Q.SIUNITX_SI`, `Q.SIUNITX_num` and `Q.SIUNITX_si`.

V1.0.2 (2020/09/07) **Minor release**

Path issues resolved. Documentation added.

V1.0.1 (2020/09/05) **Minor release**

Files renamed.

V1.0.1 (2020/09/03) **First official release.**

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