
QuantiPhy Documentation

Release 2.5.0

Ken Kundert

Jan 17, 2019

Contents

1	What?	3
2	Why?	5
3	Features	7
4	Alternatives	9
5	Quick Start	11
6	Documentation	13

Version: 2.5.0

Released: 2019-01-16

Please post all bugs and suggestions at [Github](#) (or contact me directly at quantiphy@nurdletech.com).

CHAPTER 1

What?

QuantiPhy is a Python library that offers support for physical quantities. A quantity is the pairing of a number and a unit of measure that indicates the amount of some measurable thing. *QuantiPhy* provides quantity objects that keep the units with the number, making it easy to share them as single object. They subclass float and so can be used anywhere a real number is appropriate.

CHAPTER 2

Why?

QuantiPhy naturally supports SI scale factors, which are widely used in science and engineering. SI scale factors make it possible to cleanly represent both very large and very small quantities in a form that is both easy to read and write. While generally better for humans, no general programming language provides direct support for reading or writing quantities with SI scale factors, making it difficult to write software that communicates effectively with people. *QuantiPhy* addresses this deficiency, making it natural and simple to both input and output physical quantities.

CHAPTER 3

Features

- Flexibly reads amounts with units and SI scale factors.
- Quantities subclass the *float* class and so can be used as conventional numbers.
- Generally includes the units when printing or converting to strings and by default employs SI scale factors.
- Flexible unit conversion and scaling is supported to make it easy to convert to or from any required form.
- Provides a small but extensible collection of physical constants.

Alternatives

There are a considerable number of Python packages dedicated to units and quantities (*alternatives*). However, as a rule, they focus on the units rather than the scale factors. In particular, they build a system of units that you are expected to use throughout your calculations. These packages demand a high level of commitment from their users and in turn provide unit consistency and built-in unit conversions.

In contrast, *QuantiPhy* treats units basically as documentation. They are simply strings that are attached to quantities largely so they can be presented to the user when the values are printed. As such, *QuantiPhy* is a light-weight package that demands little from the user. It is used when inputting and outputting values, and then only when it provides value. As a result, it provides a simplicity in use that cannot be matched by the other packages.

In addition, these alternative packages generally build their unit systems upon the *SI base units* <https://en.wikipedia.org/wiki/SI_base_unit>, which tends to restrict usage to physical quantities with static conversion factors. They are less suited to non-physical quantities or conversion factors that change dynamically, such as with currencies. *QuantiPhy* gracefully handles all of these cases.

CHAPTER 5

Quick Start

Install with:

```
pip3 install quantiphy
```

Requires Python3.4 or better. Python2.7 is also supported, however support for unicode is weak.

You use *Quantity* to convert numbers and units in various forms to quantities:

```
>>> from quantiphy import Quantity
>>> Tclk = Quantity(10e-9, 's')
>>> print(Tclk)
10 ns
>>> Fhy = Quantity('1420.405751786 MHz')
>>> print(Fhy)
1.4204 GHz
>>> Rsense = Quantity('1e-4Ω')
>>> print(Rsense)
100 uΩ
>>> cost = Quantity('$11_200_000')
>>> print(cost)
$11.2M
>>> Tboil = Quantity('212 °F', scale='°C')
>>> print(Tboil)
100 °C
```

Once you have a quantity, there are a variety of ways of accessing aspects of the quantity:

```
>>> Tclk.real
1e-08
```

(continues on next page)

(continued from previous page)

```
>>> float(Fhy)
1420405751.786

>>> 2*cost
22400000.0

>>> Rsense.units
'Ω'

>>> str(Tboil)
'100 °C'
```

You can use the render method to flexibly convert the quantity to a string:

```
>>> Tclk.render()
'10 ns'

>>> Tclk.render(show_units=False)
'10n'

>>> Tclk.render(form='eng', show_units=False)
'10e-9'

>>> Fhy.render(prec=8)
'1.42040575 GHz'

>>> Tboil.render(scale='°F')
'212 °F'
```

You can use the string format method or the new format strings to flexibly incorporate quantity values into strings:

```
>>> f'{Fhy}'
'1.4204 GHz'

>>> f'{Fhy:.6}'
'1.420406 GHz'

>>> f'|{Fhy:<15.6}|'
'|1.420406 GHz |'

>>> f'|{Fhy:>15.6}|'
'| 1.420406 GHz|'

>>> f'Boiling point of water: {Tboil:s}'
'Boiling point of water: 100 °C'

>>> f'Boiling point of water: {Tboil:s°F}'
'Boiling point of water: 212 °F'
```

6.1 Users' Guide

6.1.1 Overview

QuantiPhy adds support for quantities to Python. Quantities are little more than a number combined with its units. They are used to represent physical quantities. Your height and weight are both quantities, having both a value and units, and both are important. For example, if I told you that Mariam's weight was 8, you might assume pounds as the unit of measure if you lived in the US and think Mariam was an infant, or you might assume stones as the units if you live in the UK and assume that she was an adult, or you might assume kilograms if you lived anywhere else and assume she was a small child. The units are very important, and in general it is always best to keep the unit of measure with the number and present the complete value when working with quantities. To do otherwise invites confusion. Just ask [NASA](#). Readers often stumble on numbers without units as they mentally try to determine the units from context. Quantity values should be treated in a manner similar to money, which is also a quantity. Monetary amounts are almost always given with their units (a currency symbol).

Having a single object represent a quantity in a programming language is useful because it binds the units to the number making it more likely that the units will be presented with the number. In addition, quantities from *QuantiPhy* provide another important benefit. They naturally support the SI scale factors, which for those that are familiar with them are much easier to read and write than the alternatives. The most common SI scale factors are:

- T (10^{12}) tera
- G (10^9) giga
- M (10^6) mega
- k (10^3) kilo
- m (10^{-3}) milli
- μ (10^{-6}) micro
- n (10^{-9}) nano
- p (10^{-12}) pico
- f (10^{-15}) fempto
- a (10^{-18}) atto

Numbers with SI scale factors are commonly used in science and engineering to represent physical quantities because it is easy to read and write numbers both large and small. For example, the distance between the atoms in a silicon lattice is roughly 230 pm whereas the distance to the sun is about 150 Gm. Unfortunately, computers do not normally use SI scale factors. Instead, they use E-notation. The two distances would be written as 2.3e-10 m and 1.5e+11 m. Virtually all computer languages such as Python both read and write numbers in E-notation, but none naturally read or write numbers that use SI scale factors, even though SI is an [international standard](#) that has been in place for over 50 years and is widely used.

QuantiPhy is an attempt to address both of these deficiencies. It allows quantities to be represented with a single object that allows the complete quantity to be easily read or written as a single unit. It also naturally supports SI scale factors. As such, *QuantiPhy* allows computers to communicate more naturally with humans, particularly scientists and engineers.

6.1.2 Quantities

QuantiPhy is a library that adds support to Python for both reading and writing numbers with SI scale factors and units. The primary working construct for *QuantiPhy* is `quantiphy.Quantity`, which is a class whose objects hold the number and units that are used to represent a physical quantity. For example, to create a quantity from a string you can use:

```
>>> from quantiphy import Quantity

>>> distance_to_sun = Quantity('150 Gm')
>>> distance_to_sun.real
150000000000.0

>>> distance_to_sun.units
'm'

>>> print(distance_to_sun)
150 Gm
```

Now `distance_to_sun` contains an object with two values, the number 150000000000.0 and the units 'm'. The 'G' was interpreted as the *giga* scale factor, which scales 150 by 10^9 .

It is worth considering the alternative for a moment:

```
>>> d_sol = float('150000000000.0')
>>> print(f'{d_sol} m')
150000000000.0 m
```

Ignoring the difficulty in writing and reading the number, there is another important difference. The units are placed in the print statement and not kept with the number. This makes the value ambiguous, it clutters the print statement, and it introduces a vulnerability. When coming back and refactoring your code after some time has passed, you might change the units of the number and forget to change the units in the print statement. This is particularly likely if the number is defined far from where it is printed. The result is that erroneous results are printed and is always a risk when two related pieces of information are specified far from one another. *QuantiPhy* addresses this issue by binding the value and the units into one object.

`quantiphy.Quantity` is a subclass of float, and so `distance_to_sun` can be used just like any real number. For example, you can convert the distance to miles using:

```
>>> distance_in_miles = distance_to_sun / 1609.34
>>> print(distance_in_miles)
93205910.49747102
```

When printed or converted to strings quantities naturally use SI scale factors. For example, you can clean up that distance in miles using:

```
>>> distance_in_miles = Quantity(distance_to_sun / 1609.34, 'miles')
>>> print(distance_in_miles)
93.206 Mmiles
```

However, you need not explicitly do the conversion yourself. *QuantiPhy* provides many of the most common conversions for you:

```
>>> distance_in_miles = Quantity(distance_to_sun, scale='miles')
>>> print(distance_in_miles)
93.206 Mmiles
```

Specifying Quantities

Normally, creating a *quantiPHY.Quantity* takes one or two arguments. The first is taken to be the value, and the second, if given, is taken to be the model, which is a source of default values.

The First Argument: The Value

The value may be given as a float, as a string, or as a quantity. The string may be the name of a known constant or it may represent a number. If the string represents a number, it may be in floating point notation, in E-notation (ex: 1.2e+3), or use SI scale factors. It may also include the units. And like Python in general, the numbers may include underscores to make them easier to read (they are ignored). For example, any of the following ways can be used to specify 1ns:

```
>>> period = Quantity(1e-9, 's')
>>> print(period)
1 ns

>>> period = Quantity('0.000_000_001 s')
>>> print(period)
1 ns

>>> period = Quantity('1e-9s')
>>> print(period)
1 ns

>>> period = Quantity('1ns')
>>> print(period)
1 ns

>>> period2 = Quantity(period)
>>> print(period2)
1 ns
```

If given as a string, the value may also be the name of a known *constant*:

```
>>> k = Quantity('k')
>>> q = Quantity('q')
>>> print(k, q, sep='\n')
13.806e-24 J/K
160.22e-21 C
```

The following constants are pre-defined: h , k , q , c , 0°C , ϵ_0 , μ_0 , and Z_0 . You may add your own constants.

Currency units (\$€¥£₩€) are a bit different than other units, they are placed at the front of the quantity.

```
>>> print(Quantity('$11_200_000'))
$11.2M

>>> print(Quantity(11.2e6, '$'))
$11.2M
```

When using currency units, if the number has a sign, it should precede the units:

```
>>> print(Quantity('-11_200_000'))
-$11.2M

>>> print(Quantity(-11.2e6, '$'))
-$11.2M
```

When given as a string, the number may use any of the following scale factors (though you can use the *input_sf* preference to prune this list if desired):

- Y (10^{24}) yotta
- Z (10^{21}) zetta
- E (10^{18}) exa
- P (10^{15}) peta
- T (10^{12}) tera
- G (10^9) giga
- M (10^6) mega
- k (10^3) kilo
- _ (1)
- c (10^{-2}) centi
- m (10^{-3}) milli
- u (10^{-6}) micro
- μ (10^{-6}) micro
- n (10^{-9}) nano
- p (10^{-12}) pico
- f (10^{-15}) fempto
- a (10^{-18}) atto
- z (10^{-21}) zepto
- y (10^{-24}) yocto

When specifying the value as a string you may also give a name and description, and if you do they become available as the attributes *name* and *desc*. This conversion is under the control of the *assign_rec* preference. The default version of *assign_rec* accepts either '=' or ':' to separate the name from the value, and either '-', '#', or '/' to separate the value from the description if a description is given. Thus, by default *QuantiPhy* recognizes specifications of the following forms:

```
<name> = <value>
<name> = <value> -- <description>
<name> = <value> # <description>
<name> = <value> // <description>
<name>: <value>
<name>: <value> -- <description>
```

(continues on next page)

(continued from previous page)

```
<name>: <value> # <description>
<name>: <value> // <description>
```

For example:

```
>>> period = Quantity('Tclk = 10ns -- clock period')
>>> print(f'{period.name} = {period} # {period.desc}')
Tclk = 10 ns # clock period
```

The Second Argument: The Model

If you only specify a real number for the value, then the units, name, and description do not get values. Even if given as a string or quantity, the value may not contain these extra attributes. This is where the second argument, the model, helps. It may be another quantity or it may be a string. Any attributes that are not provided by the first argument are taken from the second if available. If the second argument is a string, it is split. If it contains one value, that value is taken to be the units, if it contains two, those values are taken to be the name and units, and if it contains more than two, the remaining values are taken to be the description. If the model is a quantity, only the units are inherited. For example:

```
>>> out_period = Quantity(10*period, period)
>>> print(out_period)
100 ns

>>> freq = Quantity(100e6, 'Hz')
>>> print(freq)
100 MHz

>>> freq = Quantity(100e6, 'Fin Hz')
>>> print(f'{freq.name} = {freq}')
Fin = 100 MHz

>>> freq = Quantity(100e6, 'Fin Hz input frequency')
>>> print(f'{freq.name} = {freq} -- {freq.desc}')
Fin = 100 MHz -- input frequency
```

If the model contains units, those units are only used if the value does not have units. The same is true for the description. For example:

```
>>> h = Quantity('18in', 'm')
>>> print(h)
18 in
```

The Remaining Arguments

Any arguments beyond the first two should be given as named arguments (though not a requirement at the moment, it eventually will be).

If you need to override the name, units or the description given in either the value or the model, you can do so by specifying them with corresponding named arguments. For example:

```
>>> out_period = Quantity(
...     10*period, period, name='output period',
```

(continues on next page)

(continued from previous page)

```
...     desc='period at output of frequency divider'
... )
>>> print(f'{out_period.name} = {out_period} -- {out_period.desc}')
output period = 100 ns -- period at output of frequency divider
```

In this the value is $10 \times \text{period}$, which is a float and so has no name, units, or description attributes, but the model is `period` that has all three attributes, but the name `name` and description, coming from a quantity, are ignored. As such, they specified explicitly using the `name` and `desc` named arguments.

Specifying `binary` as `True` allows you to use the binary scale factors. The binary scale factors are *Ki*, *Mi*, *Gi*, *Ti*, *Pi*, *Ei*, *Zi*, and *Yi*. Unlike the normal scale factors, you cannot use a lower case *k* in *Ki*. Also, `input_sf` is ignored. The normal recognizers are used if none of the binary scale factors are found.

```
>>> bytes = Quantity('1 KiB', binary=True)
>>> print(bytes)
1.024 kB
```

Finally, you can also specify `scale` and `ignore_sf` as named arguments. `scale` allows you to scale the value or convert it to different units. It is described *in a bit*. `ignore_sf` indicates that any scale factors should be ignored. This is one way of handling units whose name starts with a scale factor character. For example:

```
>>> x = Quantity('1m') # unitless value
>>> print(x, x.real, x.units, sep=', ')
1m, 0.001,
```

```
>>> l = Quantity('1m', ignore_sf=True) # length in meters
>>> print(l, l.real, l.units, sep=', ')
1 m, 1.0, m
```

```
>>> d = Quantity('1m', units = 'mile', ignore_sf=True) # distance in miles
>>> print(d, d.real, d.units, sep=', ')
1 mile, 1.0, mile
```

```
>>> t = Quantity('1m', units = 'min', ignore_sf=True) # duration in minutes
>>> print(t, t.real, t.units, sep=', ')
1 min, 1.0, min
```

Quantity Attributes

Finally, you can overwrite `quantiphy.Quantity` attributes to override the units, name, or description.

```
>>> out_period = Quantity(10*period)
>>> out_period.units = 's'
>>> out_period.name = 'output period'
>>> out_period.desc = 'period at output of frequency divider'
>>> print(f'{out_period.name} = {out_period} -- {out_period.desc}')
output period = 100 ns -- period at output of frequency divider
```

In addition, you can also override the preferences with attributes:

```
>>> out_period.spacer = ''
>>> print(out_period)
100ns
```

Scaling When Creating a Quantity

Quantities tend to be used primarily when reading and writing numbers, and less often when processing numbers. Often data comes in an undesirable form. For example, imagine data that has been normalized to kilograms but the numbers themselves have neither units or scale factors. *QuantiPhy* allows you to scale the number and assign the units when creating the quantity:

```
>>> mass = Quantity('2.529', scale=1000, units='g')
>>> print(mass)
2.529 kg
```

In this case the value is given in kilograms, and is converted to the base units of grams by multiplying the given value by 1000. This can also be expressed as follows:

```
>>> mass = Quantity('2.529', scale=(1000, 'g'))
>>> print(mass)
2.529 kg
```

You can also specify a function to do the conversion, which is helpful when the conversion is not linear:

```
>>> def from_dB(value, units=''):
...     return 10**(value/20), units[2:]

>>> Quantity('-100 dBV', scale=from_dB)
Quantity('10 uV')
```

The conversion can also often occur if you simply state the units you wish the quantity to have:

```
>>> Tboil = Quantity('212 °F', scale='K')
>>> print(Tboil)
373.15 K
```

This assumes that the initial value is specified with units. If not, you need to provide them for this mechanism to work.

```
>>> Tboil = Quantity('212', '°F', scale='K')
>>> print(Tboil)
373.15 K
```

To do this conversion, *QuantiPhy* examines the given units (°F) and the desired units (K) and chooses the appropriate converter. No scaling is done if the given units are the same as the desired units. Thus you can use the scaling mechanism to convert a collection of data with mixed units to values with consistent units. For example:

```
>>> weights = '''
...     240 lbs
...     230 lb
...     100 kg
...     210
... '''.strip().split('\n')
>>> for weight in weights:
...     w = Quantity(weight, 'lb', scale='lb')
...     print(w)
240 lb
230 lb
220.46 lb
210 lb
```

QuantiPhy* provides a collection of pre-defined converters for common units:

K:	K, F °F, R °R
C, °C:	K, C °C, F °F, R °R
m:	km, m, cm, mm, um μ m micron, nm, Å angstrom, mi mile miles, in inch inches
g:	oz, lb lbs
s:	sec second seconds, min minute minutes, hour hours hr, day days
b:	B

The conversions can occur between a pair of units, one from the first column and one from the second. They do not occur when both units are only in the second column. So for example, it is possible to convert between *g* and *lbs*, but not between *oz* and *lb*. However, if you notice, the units in the second column are grouped using commas. A set of units within commas are considered equivalent, meaning that there are multiple names for the same underlying unit. For example, *in*, *inch*, and *inches* are all considered equivalent. You can convert between equivalent units even though both are found in the second column. This feature was used in the above example where *lbs* was converted to *lb*.

You can also create your own converters using `quantiphy.UnitConversion`:

```
>>> from quantiphy import UnitConversion
>>> m2pc = UnitConversion('m', 'pc parsec', 3.0857e16)
>>> d_sol = Quantity('5  $\mu$ pc', scale='m')
>>> print(d_sol)
154.28 Gm
```

This unit conversion says, when converting units of ‘m’ to either ‘pc’ or ‘parsec’ multiply by 3.0857e16, when going the other way, divide by 3.0857e16.

```
>>> d_sol = Quantity('154.285 Gm', scale='pc')
>>> print(d_sol)
5 upc
```

`quantiphy.UnitConversion` supports linear conversions (slope only), affine conversions (slope and intercept) and nonlinear conversions.

Notice that the return value of `UnitConversion` was not used. It is enough to simply create the `UnitConversion` for it to be available to `Quantity`. So, it is normal to not capture the return value of `UnitConversion`. However, there are two things you can do with the return value. First you can convert it to a string to get a description of the relationship. This is largely used as a sanity check:

```
>>> print(str(m2pc))
m = 3.0857e+16*pc
```

In addition, you can use it to directly perform conversions:

```
>>> m = m2pc.convert(1, 'pc')
>>> print(str(m))
30.857e15 m

>>> kpc = m2pc.convert(30.857e+18, 'm')
>>> print(str(kpc))
1 kpc
```

You can find an example of this usage in [Cryptocurrency Example](#).

When using unit conversions it is important to only convert to units without scale factors (such as those in the first column above) when creating a quantity. For example, it is better to convert to ‘m’ rather than ‘cm’. If the desired units

used when creating a quantity includes a scale factor, then it is easy to end up with two scale factors when converting the number to a string (ex: 1 mkm or one milli-kilo-meter).

Here is an example that uses quantity rescaling. Imagine that a table is being read that gives temperature versus time, but the temperature is given in °F and the time is given in minutes, but for the purpose of later analysis it is desired that the values be converted to the more natural units of Kelvin and seconds:

```
>>> rawdata = '0 450, 10 400, 20 360'
>>> data = []
>>> for pair in rawdata.split(','):
...     time, temp = pair.split()
...     time = Quantity(time, 'min', scale='s')
...     temp = Quantity(temp, '°F', scale='K')
...     data += [(time, temp)]

>>> for time, temp in data:
...     print(f'{time:9q} {temp:9q}')
      0 s  505.37 K
     600 s  477.59 K
    1.2 ks  455.37 K
```

Creating a Quantity by Scaling an Existing Quantity

The `quantiphy.Quantity.scale()` method scales the value of a quantity and then uses the new value to create a new Quantity. For example:

```
>>> import math

>>> h_line = Quantity('1420.405751786 MHz')
>>> sagan = h_line.scale(math.pi)
>>> sagan2 = sagan.scale(2)
>>> print(sagan, sagan2, sep='\n')
4.4623 GHz
8.9247 GHz

>>> type(h_line)
<class 'quantiphy.Quantity'>

>>> type(sagan)
<class 'quantiphy.Quantity'>
```

Any value that can be passed to the `scale` argument for `quantiphy.Quantity` or `quantiphy.Quantity.render()` can be passed to the `scale` method. Specifically, the following types are accepted:

float or Quantity: The argument scales the underlying value (a new quantity is returned whose value equals the underlying quantity multiplied by scale). In this case the scale is assumed unitless (any units are ignored) and so the units of the new quantity are the same as those of the underlying quantity.

tuple: The argument consists of two values. The first value, a float, is treated as a scale factor. The second value, a string, is taken to be the units of the new quantity.

function: The function takes two arguments, the value and the units of the quantity and it returns two values, the value and units of the new value.

string: The argument is taken to be the desired units. This value along with the units of the underlying quantity are used to select a known unit conversion, which is applied to create the new value.

```
>>> Tboil_C = Tboil.scale('C')
>>> print(Tboil_C)
100 C
```

Creating a Quantity by Adding to an Existing Quantity

The `quantiphy.Quantity.add()` method adds a contribution to the value of a quantity and then uses the sum to create a new Quantity. For example:

```
>>> import math

>>> total = Quantity(0, '$')
>>> for contribution in [1.23, 4.56, 7.89]:
...     total = total.add(contribution)
>>> print(total)
$13.68
```

When adding quantities, the units of the quantity should match. You can enforce this by adding `check_units=True`. If the dimension of your quantities match but not the units, you can often use `quantiphy.Quantity.scale()` to get the units right:

```
.. code-block:: python
```

```
>>> m1 = Quantity('1kg')
>>> m2 = Quantity('1lb')
>>> m3 = m1.add(m2.scale('g'), check_units=True)
>>> print(m3)
1.4536 kg
```

Accessing Quantity Values

There are a variety of ways of accessing the value of a quantity. If you are just interested in its numeric value, you access it with:

```
>>> h_line.real
1420405751.786

>>> float(h_line)
1420405751.786
```

Or you can simply use a quantity in the same way that you would use any real number, meaning that you can use it in expressions and it evaluates to its numeric value:

```
>>> second_sagan_freq = 2 * math.pi * h_line
>>> print(second_sagan_freq)
8924672549.85517

>>> sagan2 = Quantity(second_sagan_freq, h_line)
>>> print(sagan2)
8.9247 GHz

>>> type(h_line)
<class 'quantiphy.Quantity'>
```

(continues on next page)

(continued from previous page)

```
>>> type(second_sagan_freq)
<class 'float'>

>>> type(sagan2)
<class 'quantiphy.Quantity'>
```

Notice that when performing arithmetic operations on quantities the units are completely ignored and do not propagate in any way to the newly computed result.

If you are interested in the units of a quantity, you can use:

```
>>> h_line.units
'Hz'
```

Or you can access both the value and the units, either as a tuple or in a string:

```
>>> h_line.as_tuple()
(1420405751.786, 'Hz')

>>> str(h_line)
'1.4204 GHz'
```

SI scale factors are used by default when converting numbers to strings. The following scale factors could be used:

- Y (10²⁴) yotta
- Z (10²¹) zetta
- E (10¹⁸) exa
- P (10¹⁵) peta
- T (10¹²) tera
- G (10⁹) giga
- M (10⁶) mega
- k (10³) kilo
- m (10⁻³) milli
- u (10⁻⁶) micro
- n (10⁻⁹) nano
- p (10⁻¹²) pico
- f (10⁻¹⁵) fempto
- a (10⁻¹⁸) atto
- z (10⁻²¹) zepto
- y (10⁻²⁴) yocto

However, only the scale factors listed in the *output_sf* preference are actually used, and by default that is set to 'TGMkmunpfa', which avoids the more uncommon scale factors.

The *quantiphy.Quantity.render()* method allows you to control the process of converting a quantity to a string. For example:

```
>>> h_line.render()
'1.4204 GHz'

>>> h_line.render(form='eng')
'1.4204e9 Hz'
```

(continues on next page)

(continued from previous page)

```

>>> h_line.render(show_units=False)
'1.4204G'

>>> h_line.render(form='eng', show_units=False)
'1.4204e9'

>>> h_line.render(prec=6)
'1.420406 GHz'

>>> h_line.render(form='fixed', prec=2)
'1420405751.79 Hz'

>>> bytes.render(form='binary')
'1 KiB'
    
```

show_label allows you to display the name and description of the quantity when rendering. If *show_label* is *False*, the quantity is not labeled with the name or description. Otherwise the quantity is labeled under the control of the *show_label* value and the *show_desc*, *label_fmt* and *label_fmt_full* preferences (described further in *Preferences* and *quantiphy.Quantity.set_prefs()*). If *show_label* is 'a' (for abbreviated) or if the quantity has no description, *label_fmt* is used to label the quantity with its name. If *show_label* is 'f' (for full), *label_fmt_full* is used to label the quantity with its name and description. Otherwise *label_fmt_full* is used if *show_desc* is *True* and *label_fmt* otherwise.

```

>>> freq.render(show_label=True)
'Fin = 100 MHz'

>>> freq.render(show_label='f')
'Fin = 100 MHz -- input frequency'

>>> Quantity.set_prefs(show_desc=True)
>>> freq.render(show_label=True)
'Fin = 100 MHz -- input frequency'

>>> freq.render(show_label='a')
'Fin = 100 MHz'
    
```

You can also access the full precision of the quantity:

```

>>> h_line.render(prec='full')
'1.420405751786 GHz'

>>> h_line.render(form='eng', prec='full')
'1.420405751786e9 Hz'
    
```

Full precision implies whatever precision was used when specifying the quantity if it was specified as a string and if the *keep_components* preference is *True*. Otherwise a fixed number of digits, specified in the *full_prec* preference, is used (default=12). Generally one uses 'full' when generating output that is intended to be read by a machine without loss of precision.

An alternative to *render* is *quantiphy.Quantity.fixed()*. It converts the quantity to a string in fixed-point format:

```

>>> total = Quantity('$11.2M')
>>> print(total.fixed(prec=2, show_commas=True, strip_zeros=False))
$11,200,000.00
    
```

You can also use *quantiphy.Quantity.render()* to produce a fixed format, but it does not support all of the

options available with *fixed*:

```
>>> print(total.render(form='fixed', prec=2))
$11200000
```

Another alternative to *render* is `quantiphy.Quantity.binary()`. It converts the quantity to a string that uses binary scale factors:

```
>>> mem = Quantity(17_179_869_184, 'B', name='physical memory')
>>> print(mem.binary())
16 GiB
```

Alternatively you can also use *render* to render strings with binary prefixes:

```
>>> print(mem.render(form='binary'))
16 GiB
```

Scaling When Rendering a Quantity

Once it comes time to output quantities from your program, you may again be constrained in the way the numbers must be presented. *QuantiPhy* also allows you to rescale the values as you render them to strings. In this case, the value of the quantity itself remains unchanged. For example, imagine having a quantity in grams and wanting to present it in either kilograms or in pounds:

```
>>> m = Quantity('2529 g')
>>> print('mass (kg): %s' % m.render(show_units=False, scale=0.001))
mass (kg): 2.529

>>> print(m.render(scale=(0.0022046, 'lb'), form='fixed'))
5.5754 lb
```

As before, functions can also be used to do the conversion. Here is an example where that comes in handy: a logarithmic conversion to dBV is performed.

```
>>> import math
>>> def to_dB(value, units):
...     return 20*math.log10(value), 'dB'+units

>>> T = Quantity('100mV')
>>> print(T.render(scale=to_dB))
-20 dBV
```

Finally, you can also use either the built-in converters or the converters you created to do the conversion simply based on the units:

```
>>> print(m.render(scale='lb'))
5.5755 lb
```

In an earlier example the units of time and temperature data were converted to normal SI units. Presumably this makes processing easier. Now, when producing the output, the units can be converted back to the original units if desired:

```
>>> for time, temp in data:
...     print('%-7s %s' % (time.render(scale='min'), temp.render(scale='°F')))
0 min    450 °F
10 min   400 °F
20 min   360 °F
```

String Formatting

Quantities can be passed into the string *format* method:

```
>>> print('{}'.format(h_line))
1.4204 GHz

>>> print('{:s}'.format(h_line))
1.4204 GHz
```

In these cases the preferences for SI scale factors, units, and precision are honored.

You can override the precision as part of the format specification

```
>>> print('{:.6}'.format(h_line))
1.420406 GHz
```

You can also specify the width and alignment. *QuantiPhy* follows the Python convention of right justifying numbers by default.

```
>>> print('|{:16.6}|'.format(h_line))
| 1.420406 GHz|

>>> print('|{:<16.6}|'.format(h_line))
|1.420406 GHz |

>>> print('|{:>16.6}|'.format(h_line))
| 1.420406 GHz|

>>> print('|{: ^16.6}|'.format(h_line))
| 1.420406 GHz |
```

The general form of the format specifiers supported by quantities is:

```
format_spec ::= [align][#][width][,][.precision][type][scale]
```

align specifies the alignment using one of the following characters:

Align	Meaning
>	Right justification.
<	Left justification.
^	Center justification.

The hash (#) is a literal hash that when present indicates that trailing zeros and radix should not be stripped from the fractional part of the number.

width is a literal integer that specifies the minimum width of the string.

The comma (,) is a literal comma that when present indicates that commas should be added to the whole part of the mantissa, every three digits.

precision is a literal integer that specifies the precision.

And finally, *type* specifies which form should be used when formatting the value. The choices include:

Type	Meaning
s	Use default formatting options.
q	Format using SI scale factors and show the units.
r	Format using SI scale factors but do not show the units.
p	Format using fixed-point notation and show the units.
e	Format using exponent notation but do not show the units.
f	Format using fixed-point notation but do not show the units.
b	Format using binary prefixes while showing the units.
g	Format using fixed-point or exponential notation, whichever is shorter, but do not show the units.
u	Only include the units.
n	Only include the name.
d	Only include the description.

You can capitalize any of the format characters that output the value of the quantity (any of ‘sqrpefg’, but not ‘und’). If you do, the label will also be included.

These format specifiers are generally included in format strings. However, in addition, *QuantiPhy* provides the `quantiPhy.Quantity.format()` method that converts a quantity to a string based on a naked format string. For example:

```
>>> print(h_line.format('.6q'))
1.420406 GHz
```

Here is an example of these format types:

```
>>> h_line = Quantity('f = 1420.405751786 MHz -- hydrogen line')
>>> for f in 'sSpPqQrRbBeEfFgGund':
...     print(f + ':', h_line.format(f))
s: 1.4204 GHz
S: f = 1.4204 GHz -- hydrogen line
p: 1420405751.786 Hz
P: f = 1420405751.786 Hz -- hydrogen line
q: 1.4204 GHz
Q: f = 1.4204 GHz -- hydrogen line
r: 1.4204G
R: f = 1.4204G -- hydrogen line
b: 1.3229 GiHz
B: f = 1.3229 GiHz -- hydrogen line
e: 1.4204e+09
E: f = 1.4204e+09 -- hydrogen line
f: 1420405751.786
F: f = 1420405751.786 -- hydrogen line
g: 1.4204e+09
G: f = 1.4204e+09 -- hydrogen line
u: Hz
n: f
d: hydrogen line
```

The ‘q’ type specifier is used to explicitly indicate that both the number and the units are desired and that SI scale factors should be used, regardless of the current preferences.

```
>>> print('{:.6q}'.format(h_line))
1.420406 GHz
```

Alternately, ‘r’ can be used to indicate just the number represented using SI scale factors is desired, and the units

should not be included.

```
>>> print('{:r}'.format(h_line))
1.4204G
```

The opposite can be achieved using 'p', which includes the units but not use SI scale factors:

```
>>> print('{:p}'.format(h_line))
1420405751.786 Hz
```

The 'p' format is often used with '#' to format currency values:

```
>>> print('{:#.2p}'.format(total))
$11200000.00

>>> print('{:#, .2p}'.format(total))
$11,200,000.00
```

The 'b' format is used to render number with binary scale factors:

```
>>> print('{:b}'.format(mem))
16 GiB

>>> print('{:B}'.format(mem))
physical memory = 16 GiB
```

You can also use the traditional floating point format type specifiers:

```
>>> print('{:f}'.format(h_line))
1420405751.786

>>> print('{:e}'.format(h_line))
1.4204e+09

>>> print('{:g}'.format(h_line))
1.4204e+09
```

Use 'u' to indicate that only the units are desired:

```
>>> print('{:u}'.format(h_line))
Hz
```

Access the name or description of the quantity using 'n' and 'd'.

```
>>> print('{:n}'.format(freq))
Fin

>>> print('{:d}'.format(freq))
input frequency
```

Using the upper case versions of the format codes that print the numerical value of the quantity (SQRFEg) indicates that the quantity should be labeled with its name and perhaps its description (as if the *show_label* preference were set). They are under the control of the *show_desc*, *label_fmt* and *label_fmt_full* preferences (described further in *Preferences* and *quantiphy.Quantity.set_prefs()*).

If *show_desc* is False or the quantity does not have a description, then *label_fmt* is used to add the labeling.

```

>>> Quantity.set_prefs(show_desc=False)
>>> trise = Quantity('10ns', name='trise')

>>> print('{:S}'.format(trise))
trise = 10 ns

>>> print('{:Q}'.format(trise))
trise = 10 ns

>>> print('{:R}'.format(trise))
trise = 10n

>>> print('{:F}'.format(trise))
trise = 0

>>> print('{:E}'.format(trise))
trise = 1e-08

>>> print('{:G}'.format(trise))
trise = 1e-08

>>> print('{0:n} = {0:q} ({0:d})'.format(freq))
Fin = 100 MHz (input frequency)

>>> print('{:S}'.format(freq))
Fin = 100 MHz
    
```

If `show_desc` is `True` and the quantity has a description, then `label_fmt_full` is used if the quantity has a description.

```

>>> Quantity.set_prefs(show_desc=True)

>>> print('{:S}'.format(trise))
trise = 10 ns

>>> print('{:S}'.format(freq))
Fin = 100 MHz -- input frequency
    
```

Finally, you can add units after the format code, which causes the number to be scaled to those units if the transformation represents a known unit conversion. In this case the format code must be specified (use 's' rather than '').

```

>>> Tboil = Quantity('Boiling point = 100 °C')
>>> print('{:S°F}'.format(Tboil))
Boiling point = 212 °F

>>> eff_channel_length = Quantity('leff = 14nm')
>>> print(f'{eff_channel_length:SÅ}')
leff = 140 Å

>>> print(f'{mem:bb}')
128 Gib
    
```

This feature can be used to simplify the conversion of the time and temperature information back into the original units:

```

>>> for time, temp in data:
...     print(f'{time:<7smin} {temp:s°F}')
    
```

(continues on next page)

(continued from previous page)

```
0 min 450 °F
10 min 400 °F
20 min 360 °F
```

Any format specification that is not recognized by *QuantiPhy* is simply passed on to the underlying float. For example:

```
>>> total = Quantity(1976794.98, '$')
>>> print(f'TOTAL: {total:#, .2f}')
TOTAL: 1,976,794.98
```

6.1.3 Physical Constants

QuantiPhy has several built-in constants that are available by specifying their name to the *quantiphy.Quantity* class. The following quantities are built in:

Name	MKS value	CGS value	Description
h	6.626070040e-34 J-s	6.626070040e-27 erg-s	Plank's constant
hbar,	1.054571800e-34 J-s	1.054571800e-27 erg-s	Reduced Plank's constant
k	1.38064852e-23 J/K	1.38064852e-16 erg/K	Boltzmann's constant
q	1.6021766208e-19 C	4.80320425e-10 Fr	Elementary charge
c	2.99792458e8 m/s	2.99792458e8 m/s	Speed of light
0C, 0°C	273.15 K	273.15 K	0 Celsius
eps0, ϵ_0	8.854187817e-12 F/m	—	Permittivity of free space
mu0, μ_0	4e-7 π H/m	—	Permeability of free space
Z0, Z_0	376.730313461 Ohms	—	Characteristic impedance of free space

Constants are given in base units (*g*, *m*, etc.) rather than the natural units for the unit system (*kg*, *cm*, etc.). For example, when using the CGS unit system, the speed of light is given as 300Mm/s (rather than 30Gcm/s).

As shown, these constants are partitioned into two *unit systems*: *mks* and *cgs*. Only those constants that are associated with the active unit system and those that are not associated with any unit system are available when creating a new quantity. You can activate a unit system using *quantiphy.set_unit_system()*. Doing so deactivates the previous system. By default, the *mks* system is active.

You can create your own constants and unit systems using *quantiphy.add_constant()*:

```
>>> from quantiphy import Quantity, add_constant
>>> add_constant(Quantity("\lambda: 211.061140539mm // wavelength of hydrogen line"))

>>> hy_wavelength = Quantity('\lambda')
>>> print(hy_wavelength.render(show_label=True))
\lambda = 211.06 mm -- wavelength of hydrogen line
```

In this case is the name given in the quantity is used when creating the constant. You can also specify an alias as an argument to *add_constant*.

```
>>> add_constant(
...     Quantity("\lambda = 211.061140539mm # wavelength of hydrogen line"),
...     alias='lambda h'
... )

>>> hy_wavelength = Quantity('lambda h')
>>> print(hy_wavelength.render(show_label=True))
\lambda = 211.06 mm -- wavelength of hydrogen line
```

It is not necessary to specify both the name and the alias, one is sufficient, but the constant is accessible using either. Notice that the alias does not actually become part of the constant, it is only used for looking up the constant.

By default, user defined constants are not associated with a unit system, meaning that they are always available regardless of which unit system is being used. However, when creating a constant you can specify one or more unit systems for the constant. You need not limit yourself to the predefined *mks* and *cgs* unit systems. You can specify multiple unit systems either by specifying a list of strings for the unit systems, or by specifying one string that would contain more than one name once split.

```
>>> from quantiphy import Quantity, add_constant, set_unit_system

>>> add_constant(Quantity(4.80320427e-10, 'Fr'), 'q', 'esu gaussian')
>>> add_constant(Quantity(1.602176487e-20, 'abC'), alias='q', unit_systems='emu')
>>> q_mks = Quantity('q')
>>> set_unit_system('cgs')
>>> q_cgs = Quantity('q')
>>> set_unit_system('esu')
>>> q_esu = Quantity('q')
>>> set_unit_system('gaussian')
>>> q_gaussian = Quantity('q')
>>> set_unit_system('emu')
>>> q_emu = Quantity('q')
>>> set_unit_system('mks')
>>> print(q_mks, q_cgs, q_esu, q_gaussian, q_emu, sep='\n')
160.22e-21 C
480.32 pFr
480.32 pFr
480.32 pFr
16.022e-21 abC
```

6.1.4 Preferences

QuantiPhy supports a wide variety of preferences that control its behavior. For example, when rendering quantities you can control the number of digits used (*prec*), whether SI scale factors are used (*form*), whether the units are included (*show_units*), etc. Similar preferences also control the conversion of strings into quantities, which can help disambiguate whether a suffix represents a scale factor or a unit. The list of available preferences and their descriptions are given in the description of the `quantiphy.Quantity.set_prefs()` method.

To set a preference, use the `quantiphy.Quantity.set_prefs()` class method. You can set more than one preference at once:

```
>>> Quantity.set_prefs(prec=6, map_sf={'u': '\u03bc'})
```

This statements tells *QuantiPhy* to use 7 digits (the *prec* plus 1) and to output μ rather u for the 10^{-6} scale factor.

Setting preferences to *None* returns them to their default values:

```
>>> Quantity.set_prefs(prec=None, map_sf=None)
```

The preferences are changed on the class itself, meaning that they affect any instance of that class regardless of whether they were instantiated before or after the preferences were set. If you would like to have more than one set of preferences, then you should subclass `quantiphy.Quantity`. For example, imagine a situation where you have different types of quantities that would naturally want different precisions:

```
>>> class Temperature(Quantity):
...     pass
```

(continues on next page)

(continued from previous page)

```

>>> Temperature.set_prefs(prec=1, known_units='K', spacer='')

>>> class Frequency(Quantity):
...     pass
>>> Frequency.set_prefs(prec=5, spacer='')

>>> frequencies = []
>>> for each in '-25.3 999987.7, 25.1 1000207.1, 74.9 1001782.3'.split(','):
...     temp, freq = each.split()
...     frequencies.append((Temperature(temp, 'C'), Frequency(freq, 'Hz')))

>>> for temp, freq in frequencies:
...     print(f'{temp:4} {freq}')
-25C 999.988kHz
 25C 1.00021MHz
 75C 1.00178MHz
    
```

In this example, a subclass is created that is intended to report in concentrations.

```

>>> class Concentration(Quantity):
...     pass
>>> Concentration.set_prefs(
...     map_sf = dict(u=' PPM', n= ' PPB', p=' PPT'),
...     show_label = True,
... )

>>> pollutants = dict(CO=5, SO2=20, NO2=0.10)
>>> concentrations = [Concentration(v, scale=1e-6, name=k) for k, v in pollutants.
->items()]
>>> for each in concentrations:
...     print(each)
CO = 5 PPM
SO2 = 20 PPM
NO2 = 100 PPB
    
```

When a subclass is created, the preferences active in the main class are copied into the subclass. Subsequent changes to the preferences in the main class do not affect the subclass.

You can also go the other way and override the preferences on a specific quantity.

```

>>> print(hy_wavelength)
211.06 mm

>>> hy_wavelength.show_label = True
>>> print(hy_wavelength)
λ = 211.06 mm -- wavelength of hydrogen line
    
```

This is often the way to go with quantities that have logarithmic units such as decibels (dB) or shannons (Sh) (or the related bit, digits, nats, hartleys, etc.). In these cases use of SI scale factors is often undesired.

```

>>> gain = Quantity(0.25, 'dB')
>>> print(gain)
250 mdB

>>> gain.form = 'eng'
>>> print(gain)
250e-3 dB
    
```

To retrieve a preference, use the `quantiphy.Quantity.get_pref()` class method. This is useful with `known_units`. Normally setting `known_units` overrides the existing units. You can simply add more with:

```
>>> Quantity.set_prefs(known_units=Quantity.get_pref('known_units') + ['K'])
```

A variation on `quantiphy.Quantity.set_prefs()` is `quantiphy.Quantity.prefs()`. It is basically the same, except that it is meant to work with Python's `with` statement to temporarily override preferences:

```
>>> with Quantity.prefs(form='fixed', show_units=False, prec=2):
...     for time, temp in data:
...         print('%-7s %s' % (time, temp))
0         505.37
600      477.59
1200     455.37

>>> print('Final temperature = %s @ %s.' % data[-1][::-1])
Final temperature = 455.37 K @ 1.2 ks.
```

Notice that the specified preferences only affected the table, not the final printed values, which were rendered outside the `with` statement.

6.1.5 Ambiguity of Scale Factors and Units

By default, *QuantiPhy* treats both the scale factor and the units as being optional. With the scale factor being optional, the meaning of some specifications can be ambiguous. For example, '1m' may represent 1 milli or it may represent 1 meter. Similarly, '1meter' may represent 1 meter or 1 milli-eter. In this case *QuantiPhy* gives preference to the scale factor, so '1m' normally converts to 1e-3. To allow you to avoid this ambiguity, *QuantiPhy* accepts '_' as the unity scale factor. In this way '1_m' is unambiguously 1 meter. You can instruct *QuantiPhy* to output '_' as the unity scale factor by specifying the `unity_sf` argument to `quantiphy.Quantity.set_prefs()`:

```
>>> Quantity.set_prefs(unity_sf='_', spacer='')
>>> l = Quantity(1, 'm')
>>> print(l)
1_m
```

This is often a good way to go if you are outputting numbers intended to be read by people and machines.

If you need to interpret numbers that have units and are known not to have scale factors, you can specify the `ignore_sf` preference:

```
>>> Quantity.set_prefs(ignore_sf=True, unity_sf='', spacer=' ')
>>> l = Quantity('1000m')
>>> l.as_tuple()
(1000.0, 'm')

>>> print(l)
1 km

>>> Quantity.set_prefs(ignore_sf=False)
>>> l = Quantity('1000m')
>>> l.as_tuple()
(1.0, '')
```

If there are scale factors that you know you will never use, you can instruct *QuantiPhy* to interpret a specific set and ignore the rest using the `input_sf` preference.

```
>>> Quantity.set_prefs(input_sf='GMk')
>>> l = Quantity('1000m')
>>> l.as_tuple()
(1000.0, 'm')

>>> print(l)
1 km
```

Specifying `input_sf=None` causes *QuantiPhy* to again accept all known scale factors again.

```
>>> Quantity.set_prefs(input_sf=None)
>>> l = Quantity('1000m')
>>> l.as_tuple()
(1.0, '')
```

Alternatively, you can specify the units you wish to use whose leading character is a scale factor. Once known, these units no longer confuse *QuantiPhy*. These units can be specified as a list or as a string. If specified as a string the string is split to form the list. Specifying the known units replaces any existing known units.

```
>>> d1 = Quantity('1 au')
>>> d2 = Quantity('1000 pc')
>>> print(d1.render(form='eng'), d2, sep='\n')
1e-18 u
1 nc

>>> Quantity.set_prefs(known_units='au pc')
>>> d1 = Quantity('1 au')
>>> d2 = Quantity('1000 pc')
>>> print(d1.render(form='eng'), d2, sep='\n')
1 au
1 kpc
```

This same issue comes up for temperature quantities when given in Kelvin. There are again several ways to handle this. First you can specify the acceptable input scale factors leaving out 'K', ex. `input_sf = 'TGMkmunpfa'`. Alternatively, you can specify 'K' as one of the known units. Finally, if you know exactly when you will be converting a temperature to a quantity, you can specify `ignore_sf` for that specific conversion. The effect is the same either way, 'K' is interpreted as a unit rather than a scale factor.

6.1.6 Formatting Tabular Data

When creating tables it is often desirable to align the decimal points of the numbers, and perhaps align the units. You can use the `number_fmt` to arrange this. `number_fmt` is a format string that if specified is used to convert the components of a number into the final number. You can control the widths and alignments of the components to implement specific arrangements. `number_fmt` is passed to the string `format` function with named arguments: `whole`, `frac` and `units`, which contains the integer part of the number, the fractional part including the decimal point, and the units including the scale factor. More information about the content of the components can be found in `quantiphy.Quantity.set_prefs()`.

For example, you can align the decimal point and units of a column of numbers like this:

```
>>> lengths = [
...     Quantity(1)
...     for l in '1mm, 10mm, 100mm, 1.234mm, 12.34mm, 123.4mm'.split(',')
... ]
```

(continues on next page)

(continued from previous page)

```

>>> with Quantity.prefs(number_fmt='{whole:>3}{frac:<4} {units}'):
...     for l in lengths:
...         print(l)
1      mm
10     mm
100    mm
1.234 mm
12.34  mm
123.4  mm
    
```

You can also give a function as the value for *number_fmt* rather than a string. It would be called with *whole*, *frac* and *units* as arguments given in that order. The function is expected to return the assembled number as a string. For example:

```

>>> def fmt_num(whole, frac, units):
...     return '{mantissa:<5} {units}'.format(mantissa=whole+frac, units=units)

>>> with Quantity.prefs(number_fmt=fmt_num):
...     for l in lengths:
...         print(l)
1      mm
10     mm
100    mm
1.234 mm
12.34  mm
123.4  mm
    
```

If there are multiple columns it might be necessary to apply a different format to each column. In this case, it often makes sense to create a subclass of *Quantity* for each column that requires distinct formatting:

```

>>> def format_temperature(whole, frac, units):
...     return '{:>5} {:<5}'.format(whole+frac, units)

>>> class Temperature(Quantity):
...     pass
>>> Temperature.set_prefs(
...     prec = 1, known_units = 'K', number_fmt = format_temperature
... )

>>> class Frequency(Quantity):
...     pass
>>> Frequency.set_prefs(prec=5, number_fmt = '{whole:>3}{frac:<6} {units}')

>>> frequencies = []
>>> for each in '-25.3 999987.7, 25.1 1000207.1, 74.9 1001782.3'.split(','):
...     temp, freq = each.split()
...     frequencies.append((Temperature(temp, 'C'), Frequency(freq, 'Hz')))

>>> for temp, freq in frequencies:
...     print(temp, freq)
-25 C      999.988  kHz
25 C       1.00021 MHz
75 C       1.00178 MHz
    
```

6.1.7 Extract Quantities

It is possible to put a collection of quantities in a text string and then use the `quantiphy.Quantity.extract()` method to parse the quantities and return them in a dictionary. For example:

```
>>> design_parameters = '''
...     Fref (f) = 156 MHz  -- Reference frequency
...     Kdet = 88.3 uA     -- Gain of phase detector
...     Kvco = 9.07 GHz/V  -- Gain of VCO
... '''
>>> quantities = Quantity.extract(design_parameters)

>>> Quantity.set_prefs(
...     label_fmt='{n} = {v}',
...     label_fmt_full='{V:<18} # {d}',
...     show_label='f',
... )
>>> for k, q in quantities.items():
...     print(f'{k}: {q}')
Fref: f = 156 MHz      # Reference frequency
Kdet: Kdet = 88.3 uA   # Gain of phase detector
Kvco: Kvco = 9.07 GHz/V # Gain of VCO
```

The string is processed one line at a time and may contain any number of quantity definitions. Blank lines are ignored. Each non-blank line is passed through `assign_rec` to determine if it is recognized as an assignment. If it is recognized, the `assign_rec` named fields (`name`, `qname`, `val`, and `desc`) are used when creating the quantity. The default recognizer allows you to separate the name from the value with either '=' or ':'. It allows you to separate the value from the description using '-', '/', or '#'. These substrings are also used to introduce comments, so you could start a line with '#' and it would be treated as a comment. If the line is not recognized, then it is ignored.

In this example, the first line is nonconforming and so is ignored. The second `Kvdo` line is a comment, the comment character and anything beyond is ignored. Finally, empty lines are ignored.

```
>>> design_parameters = '''
...     PLL Design Parameters
...
...     Fref = 156 MHz      -- Reference frequency
...     Kdet = 88.3 uA     -- Gain of phase detector
...     Kvco = 9.07 GHz/V  -- Gain of VCO
...     -- Kvco = 5 GHz/V  -- Gain of VCO
...     N = 128           -- Divide ratio
...     Fout = N*Fref "Hz" -- Output Frequency
... '''
>>> globals().update(Quantity.extract(design_parameters))

>>> print(f'{Fref:S}\n{Kdet:S}\n{Kvco:S}\n{N:S}\n{Fout:}')
Fref = 156 MHz      # Reference frequency
Kdet = 88.3 uA     # Gain of phase detector
Kvco = 9.07 GHz/V  # Gain of VCO
N = 128           # Divide ratio
Fout = 19.968 GHz  # Output Frequency
```

In this case the output of the `quantiphy.Quantity.extract()` call is fed into `globals().update()` so as to add the quantities into the module namespace, making the quantities accessible as local variables. This is an example of how simulation scripts could be written. The system and simulation parameters would be gathered together at the top into a multiline string, which would then be read and loaded into the local name space. It allows you to quickly give a complete description of a collection of parameters when the goal is to put something together quickly in an expressive manner. Another example of this ideas is shown a bit further down where the module docstring is used to contain the

quantity definitions.

Here is an example that uses this feature to read parameters from a file. This is basically the same idea as above, except the design parameters are kept in a separate file. It also subclasses `quantiPHY.Quantity` to create a version that displays the name and description by default.

```
>>> from quantiPHY import Quantity, InvalidNumber
>>> from inform import os_error, fatal, display

>>> class VerboseQuantity(Quantity):
...     show_label = 'f'
...     label_fmt = '{n} = {v}'
...     label_fmt_full = '{V:<18} -- {d}'

>>> filename = 'parameters'
>>> try:
...     with open(filename) as f:
...         globals().update(VerboseQuantity.extract(f.read()))
... except OSError as e:
...     fatal(os_error(e))
... except InvalidNumber as e:
...     fatal(e, culprit=filename)

>>> display(Fref, Kdet, Kvco, N, Fout, sep='\n')
Fref = 156 MHz      -- Reference frequency
Kdet = 88.3 uA     -- Gain of phase detector (Imax)
Kvco = 9.07 GHz/V  -- Gain of VCO
N = 128           -- Divide ratio
Fout = 19.968 GHz  -- Output Frequency
```

With `quantiPHY.Quantity.extract()` the values of quantities can be given as an expression that contains previously defined quantities (or *physical constants* or select mathematical constants (π , τ , or τ)). You can follow an expression with a string to give the units. Finally, you can use the *predefined* argument to pass in a dictionary of named values that can be used in your expressions. For example:

```
#!/usr/bin/env python3
>>> __doc__ = """
... Simulates a second-order  $\Delta\Sigma$  modulator with the following parameter values:
...
...     Fclk = Fxtal/4 "Hz"           -- clock frequency
...     Fin = 200kHz                 -- input frequency
...     Vin = 950mV                  -- input voltage amplitude (peak)
...     gain1 = 0.5V/V               -- gain of first integrator
...     gain2 = 0.5V/V               -- gain of second integrator
...     Vmax = 1V                    -- quantizer maximum input voltage
...     Vmin = -1V                   -- quantizer minimum input voltage
...     levels = 5                   -- quantizer output levels
...     Tstop = 2/Fin "s"            -- simulation stop time
...     Tstart = -1/Fin 's'          -- initial transient interval (discarded)
...     file_name = 'out.wave'       -- output filename
...     sim_name = f'{Fclk:q}  $\Delta\Sigma$  Modulator' -- simulation name
...
... The values given above are used in the simulation, no further
... modification of the code given below is required when changing
... these parameters.
... """

>>> from quantiPHY import Quantity
```

(continues on next page)

(continued from previous page)

```

>>> Fxtal = Quantity('200 MHz')
>>> parameters = Quantity.extract(__doc__, predefined=dict(Fxtal=Fxtal))
>>> globals().update(parameters)

>>> with Quantity.prefs(
...     label_fmt='{n} = {v}',
...     label_fmt_full='{V:<18} -- {d}',
...     show_label='f',
... ):
...     print('Simulation parameters:')
...     for k, v in parameters.items():
...         try:
...             print(f'    {v:Q}')
...         except ValueError:
...             print(f'    {k} = {v!s}')
Simulation parameters:
    Fclk = 50 MHz      -- clock frequency
    Fin = 200 kHz     -- input frequency
    Vin = 950 mV      -- input voltage amplitude (peak)
    gain1 = 500 mV/V  -- gain of first integrator
    gain2 = 500 mV/V  -- gain of second integrator
    Vmax = 1 V        -- quantizer maximum input voltage
    Vmin = -1 V       -- quantizer minimum input voltage
    levels = 5        -- quantizer output levels
    Tstop = 10 us     -- simulation stop time
    Tstart = -5 us    -- initial transient interval (discarded)
    file_name = out.wave
    sim_name = 50 MHz  $\Delta\Sigma$  Modulator
    
```

Notice in this case the parameters were specified and read out of the docstring at the top of the file. In this way, the parameters become very easy to set and the documentation is always up to date. Ignore the fact that the docstring is assigned to `__doc__`. That was a hack that was needed to make the example executable from within the documentation.

6.1.8 Translating Quantities

`quantiphy.Quantity.all_from_conv_fmt()` recognizes conventionally formatted numbers and quantities embedded in text and reformats them using `quantiphy.Quantity.render()`. This is an difficult task in general, and so some constraints are placed on the values to make them easier to distinguish. Specifically, the units, if given, must be simple and immediately adjacent to the number. Units are simple if they only consist of letters and underscores. The characters $^\circ$, \AA , Ω and U are also allowed. So '47e3Ohms', '50_Ohms' and '1.0e+12 Ω ' are recognized as quantities, but '50 Ohms' and '12m/s' are not.

Besides the text to be translated, `all_from_conv_fmt()` takes the same arguments as `render()`, though they must be given as named arguments.

```

>>> test_results = '''
... Applying stimulus @ 2.00500000e-04s: V(in) = 5.000000e-01V.
... Pass @ 3.00500000e-04s: V(out): expected=2.00000000e+00V, measured=1.
... ↪99999965e+00V, diff=3.46117130e-07V.
... '''.strip()

>>> Quantity.set_prefs(spacer='')
>>> translated = Quantity.all_from_conv_fmt(test_results)
>>> print(translated)
    
```

(continues on next page)

(continued from previous page)

```
Applying stimulus @ 200.5us: V(in) = 500mV.
Pass @ 300.5us: V(out): expected=2V, measured=2V, diff=346.12nV.
```

`quantiphy.Quantity.all_from_si_fmt()` is similar, except that it recognizes quantities formatted with either a scale factor or units and ignores plain numbers. Again, units are expected to be simple and adjacent to their number.

```
>>> Quantity.set_prefs(spacer='')
>>> translated_back = Quantity.all_from_si_fmt(translated, form='eng')
>>> print(translated_back)
Applying stimulus @ 200.5e-6s: V(in) = 500e-3V.
Pass @ 300.5e-6s: V(out): expected=2V, measured=2V, diff=346.12e-9V.
```

Notice in the translations the quantities lost resolution. This is avoided if you use 'full' precision:

```
>>> translated = Quantity.all_from_conv_fmt(test_results, prec='full')
>>> print(translated)
Applying stimulus @ 200.5us: V(in) = 500mV.
Pass @ 300.5us: V(out): expected=2V, measured=1.99999965V, diff=346.11713nV.
```

6.1.9 Equivalence

You can determine whether the value of a quantity or real number is equivalent to that of a quantity using `quantiphy.Quantity.is_close()`. The two values need not be identical, they just need to be close to be deemed equivalent. The `reltol` and `abstol` preferences are used to determine if they are close.

```
>>> h_line.is_close(h_line)
True

>>> h_line.is_close(h_line + 1)
True

>>> h_line.is_close(h_line + 1e4)
False
```

`quantiphy.Quantity.is_close()` returns true if the units match and if:

$$\text{abs}(a - b) \leq \max(\text{reltol} * \max(\text{abs}(a), \text{abs}(b)), \text{abstol})$$

where *a* and *b* represent *other* and the numeric value of the underlying quantity.

By default, `is_close()` looks at the both the value and the units if the argument has units. In this way if you compare two quantities with different units, the `is_close()` test will always fail if their units differ. This behavior can be overridden by specifying `check_units`.

```
>>> Quantity('$10').is_close(Quantity('10 USD'))
False

>>> Quantity('$10').is_close(Quantity('10 USD'), check_units=False)
True
```

6.1.10 Exceptional Values

QuantiPhy supports NaN (not a number) and infinite values:

```
>>> inf = Quantity('inf Hz')
>>> print(inf)
inf Hz
```

```
>>> nan = Quantity('NaN Hz')
>>> print(nan)
nan Hz
```

You can test whether the value of the quantity is infinite or is not-a-number using `quantiphy.Quantity.is_infinite()` or `quantiphy.Quantity.is_nan()`:

```
>>> h_line.is_infinite()
False

>>> inf.is_infinite()
True

>>> h_line.is_nan()
False

>>> nan.is_nan()
True
```

6.1.11 Exceptions

The way exceptions are defined in *QuantiPhy* has changed. Initially, the standard Python exceptions were used to indicate errors. For example, a *ValueError* was raised by `quantiphy.Quantity` if it were passed a string it cannot convert into a number. Now, a variety of *QuantiPhy* specific exceptions are used to indicate specific errors. However, these exceptions subclass the corresponding Python error for compatibility with existing code. It is recommended that new code catch the *QuantiPhy* specific exceptions rather than the generic Python exceptions as their use may be deprecated in the future.

QuantiPhy employs the following exceptions:

`quantiphy.ExpectedQuantity`: Subclass of `quantiphy.QuantiPhyError` and `ValueError`. Used by `quantiphy.add_constant()`.

Raised when the value is either not an instance of `quantiphy.Quantity` or a string that can be converted to a quantity.

`quantiphy.IncompatibleUnits`: Subclass of `quantiphy.QuantiPhyError` and `TypeError`. Used by `quantiphy.Quantity.add()`.

Raised when the units of contribution do not match those of underlying quantity.

`quantiphy.InvalidNumber`: Subclass of `quantiphy.QuantiPhyError`, `ValueError`, and `TypeError`. Used by `quantiphy.Quantity()`.

Raised if the value given could not be converted to a number.

`quantiphy.InvalidRecognizer`: Subclass of `quantiphy.QuantiPhyError` and `KeyError`. Used by `quantiphy.Quantity()`.

The `assign_rec` preference is expected to be a regular expression that defines one or more named fields, one of which must be `val`. This exception is raised when the current value of `assign_rec` does not satisfy this requirement.

quantiphy.MissingName: Subclass of `quantiphy.QuantiPhyError` and `NameError`. Used by `quantiphy.add_constant()`.

Raised when *alias* was not specified and no name was available from *value*.

quantiphy.UnknownConversion: Subclass of `quantiphy.QuantiPhyError` and `KeyError`.

Used by `quantiphy.UnitConversion.convert()`.

Raised when the given units are not supported by the underlying class.

Used by `quantiphy.Quantity()`, `quantiphy.Quantity.scale()`, `quantiphy.Quantity.render()`, `quantiphy.Quantity.fixed()`, and `quantiphy.Quantity.format()`.

Raised when a unit conversion was requested and there is no corresponding unit converter.

quantiphy.UnknownFormatKey: Subclass of `quantiphy.QuantiPhyError` and `KeyError`. Used by `quantiphy.Quantity.render()`, `quantiphy.Quantity.fixed()`, and `quantiphy.Quantity.format()`.

The *label_fmt* and *label_fmt_full* are expected to be format strings that may interpolate certain named arguments. The valid named arguments are *n* for name, *v* for value, and *d* for description. This exception is raised when some other name is used for an interpolated argument.

quantiphy.UnknownPreference: Subclass of `quantiphy.QuantiPhyError` and `KeyError`. Used by `quantiphy.Quantity.set_prefs()`, `quantiphy.Quantity.get_pref()`, and `quantiphy.Quantity.prefs()`.

Raised when the name given for a preference is unknown.

quantiphy.UnknownScaleFactor: Subclass of `quantiphy.QuantiPhyError` and `ValueError`. Used by `quantiphy.Quantity()`, `quantiphy.Quantity.set_prefs()`, or `quantiphy.Quantity.prefs()`.

The *input_sf* preference gives the list of scale factors that should be accepted. This exception is raised if *input_sf* contains an unknown scale factor.

quantiphy.UnknownUnitSystem: Subclass of `quantiphy.QuantiPhyError` and `KeyError`. Used by `quantiphy.set_unit_system()`.

Raised when the name given does not correspond to a known unit system.

`QuantiPhy` defines a common base exception, `quantiphy.QuantiPhyError`, that all specific exceptions derive from. This allows you to simplify your exception handling if you are not interested in distinguishing between the specific errors:

```
>>> from quantiphy import Quantity, QuantiPhyError

>>> try:
...     q = Quantity('tweed')
... except QuantiPhyError as e:
...     print(str(e))
tweed: not a valid number.
```

The alternative would be to catch each error individually:

```
>>> from quantiphy import (
...     Quantity, InvalidNumber, UnknownScaleFactor,
...     UnknownConversion, InvalidRecognizer
... )
```

```
>>> try:
...     q = Quantity('tweed')
... except (InvalidNumber, UnknownScaleFactor, UnknownConversion, InvalidRecognizer):
↳ as e:
...     print(str(e))
tweed: not a valid number.
```

6.2 Classes and Functions

6.2.1 Quantities

class `quantiphy.Quantity`

Create a Physical Quantity

A quantity is a number paired with a unit of measure.

Parameters

- **value** (*real, string or quantity*) – The value of the quantity. If a string, it may be the name of a pre-defined constant or it may be a number that may be specified with SI scale factors and/or units. For example, the following are all valid: ‘2.5ns’, ‘1.7 MHz’, ‘1e6Ω’, ‘2.8_V’, ‘1e4 m/s’, ‘\$10_000’, ‘42’, ‘’, etc. The string may also have name and description if they are provided in a way recognizable by *assign_rec*. For example, ‘trise: 10ns – rise time’ or ‘trise = 10ns # rise time’ would work with the default recognizer.
- **model** (*quantity or string*) – Used to pick up any missing attributes (*units, name, desc*). May be a quantity or a string. If model is a quantity, only its units would be taken. If model is a string, it is split. Then, if there is one item, it is taken to be *units*. If there are two, they are taken to be *name* and *units*. And if there are three or more, the first two are taken to be *name* and *units*, and the remainder is taken to be *description*.
- **units** (*str*) – Overrides the units taken from *value* or *model*.
- **scale** (*float, tuple, func, string, or quantity*) –
 - If a float or quantity, it multiplies by the given value to compute the value of the quantity. If a quantity, the units are ignored.
 - If a tuple, the first value, a float, is treated as a scale factor and the second value, a string, is take to be the units of the quantity.
 - If a function, it takes two arguments, the given value and the units and it returns two values, the value and units of the quantity.
 - If a string, it is taken to the be desired units. This value along with the units of the given value are used to select a known unit conversion, which is applied to create the quantity.
- **name** (*str*) – Overrides the name taken from *value* or *model*.
- **desc** (*str*) – Overrides the desc taken from *value* or *model*.
- **ignore_sf** (*bool*) – Assume the value given within a string does not employ a scale factors. In this way, ‘1m’ is interpreted as 1 meter rather than 1 milli.
- **binary** (*bool*) – Allow use of binary scale factors (Ki, Mi, Gi, Ti, Pi, Ei, Zi, Yi).

Raises

- **`UnknownConversion(QuantiPhyError, KeyError)`** – A unit conversion was requested and there is no corresponding unit converter.
- **`InvalidRecognizer(QuantiPhyError, KeyError)`** – Assignment recognizer (*assign_rec*) does not match at least the value (*val*).
- **`UnknownScaleFactor(QuantiPhyError, ValueError)`** – Unknown scale factor.
- **`InvalidNumber(QuantiPhyError, ValueError, TypeError)`** – Not a valid number.

You can use *Quantity* to create quantities from floats, strings, or other quantities. If a float is given, *model* or *units* would be used to specify the units.

Examples:

```
>>> from quantiphy import Quantity
>>> from math import pi, tau
>>> newline = '''
... '''

>>> fhy = Quantity('1420.405751786 MHz')
>>> sagan = Quantity(pi*fhy, 'Hz')
>>> sagan2 = Quantity(tau*fhy, fhy)
>>> print(fhy, sagan, sagan2, sep=newline)
1.4204 GHz
4.4623 GHz
8.9247 GHz
```

You can use *scale* to scale the number or convert to different units when creating the quantity.

Examples:

```
>>> Tfreeze = Quantity('273.15 K', ignore_sf=True, scale='°C')
>>> print(Tfreeze)
0 °C

>>> Tboil = Quantity('212 °F', scale='°C')
>>> print(Tboil)
100 °C
```

`add` (*addend*, *check_units=False*)

Create a new quantity that is the sum of the original and a contribution.

Parameters

- **`addend`** (*boolean* or *'strict'*) – The amount to add to the quantity.
- **`check_units`** – If True, raise a *TypeError* if the units of the *addend* are not compatible with the underlying quantity. If the *addend* does not have units, then it is considered compatible unless *check_units* is 'strict'.

Raises *IncompatibleUnits* (*TypeError*) – Units of contribution do not match those of underlying quantity.

Example:

```
>>> total = Quantity(0, '$')
>>> for contribution in [1.23, 4.56, 7.89]:
...     total = total.add(contribution)
```

(continues on next page)

(continued from previous page)

```
>>> print(total)
$13.68
```

classmethod `all_from_conv_fmt` (*text*, ***kwargs*)

Convert all numbers and quantities from conventional notation.

Parameters

- **text** (*str*) – A search and replace is performed on this text. The search looks for numbers and quantities in floating point or e-notation. They are replaced with the same number rendered as a quantity. To be recognized any units must be simple (only letters or underscores, no digits or symbols) and the units must be immediately adjacent to the number.
- ****kwargs** – By default the numbers are rendered using the currently active preferences, but any valid argument to `Quantity.render()` can be passed in to control the rendering.

Returns A copy of *text* where all numbers that were formatted conventionally have been reformatted.

Return type `str`

Example:

```
>>> text = 'Applying stimulus @ 2.05000e-05s: V(in) = 5.00000e-01V.'
>>> with Quantity.prefs(spacer=''):
...     xlated = Quantity.all_from_conv_fmt(text)
...     print(xlated)
Applying stimulus @ 20.5us: V(in) = 500mV.
```

classmethod `all_from_si_fmt` (*text*, ***kwargs*)

Convert all numbers and quantities from SI notation.

Parameters

- **text** (*str*) – A search and replace is performed on this text. The search looks for numbers and quantities formatted in SI notation (must have either a scale factor or units or both). They are replaced with the same number rendered as a quantity. To be recognized any units must be simple (only letters or underscores, no digits or symbols) and the units must be immediately adjacent to the number.
- ****kwargs** – By default the numbers are rendered using the currently active preferences, but any valid argument to `Quantity.render()` can be passed in to control the rendering.

Returns A copy of *text* where all numbers that were formatted with SI scale factors have been reformatted.

Return type `str`

Example:

```
>>> print(Quantity.all_from_si_fmt(xlated))
Applying stimulus @ 20.5 us: V(in) = 500 mV.

>>> print(Quantity.all_from_si_fmt(xlated, form='eng'))
Applying stimulus @ 20.5e-6 s: V(in) = 500e-3 V.
```

as_tuple ()

Returns a tuple that contains the value as a float along with its units.

Example:

```
>>> period = Quantity('10ns')
>>> period.as_tuple()
(1e-08, 's')
```

binary (*show_units=None, prec=None, show_label=None, strip_zeros=None, strip_radix=None, scale=None*)

Convert quantity to string using binary scale factors.

When in range the number is divided by some integer power of 1024 and the appropriate scale factor is added to the quotient, where the scale factors are ‘’ for 0 powers of 1024, ‘Ki’ for 1, ‘Mi’ for 2, ‘Gi’ for 3, ‘Ti’ for 4, ‘Pi’ for 5, ‘Ei’ for 6, ‘Zi’ for 7 and ‘Yi’ for 8. Outside this range, the number is converted to a string using a simple floating point format.

Within the range the number of significant figures used is equal to `prec+1`. Outside the range, `prec` give the number of figures to the right of the decimal point.

Parameters

- **show_units** (*bool*) – Whether the units should be included in the string.
- **prec** (*integer or 'full'*) – The desired precision (number of digits to the right or the radix). If specified as ‘full’, the full original precision is used.
- **show_label** (*'f', 'a', or boolean*) – Add the name and possibly the description when rendering a quantity to a string. Either *label_fmt* or *label_fmt_full* is used to label the quantity.
 - neither is used if *show_label* is False,
 - otherwise *label_fmt* is used if quantity does not have a description or if *show_label* is ‘a’ (short for abbreviated),
 - otherwise *label_fmt_full* is used if *show_desc* is True or *show_label* is ‘f’ (short for full).
- **strip_zeros** (*boolean*) – Remove contiguous zeros from end of fractional part. If not specified, the global *strip_zeros* setting is used.
- **strip_radix** (*boolean*) – Remove radix if there is nothing to the right of it. If not specified, the global *strip_radix* setting is used.
- **scale** (*real, pair, function, or string*) –
 - If a float, it scales the displayed value (the quantity is multiplied by *scale* before being converted to the string).
 - If a tuple, the first value, a float, is treated as a scale factor and the second value, a string, is take to be the units of the displayed value.
 - If a function, it takes two arguments, the value and the units of the quantity and it returns two values, the value and units of the displayed value.
 - If a string, it is taken to the be desired units. This value along with the units of the quantity are used to select a known unit conversion, which is applied to create the displayed value.

Raises

- **UnknownConversion** (**QuantiPhyError**, **KeyError**) – A unit conversion was requested and there is no corresponding unit converter.

- **UnknownFormatKey** (*QuantityError*, *KeyError*) – ‘label_fmt’ or ‘label_fmt_full’ contains an unknown format key.

Example:

```
>>> t = Quantity('mem = 16 GiB -- amount of physical memory', binary=True)
>>> print(
...     t.binary(),
...     t.binary(prec=3, strip_zeros=False),
...     t.binary(show_label=True, scale='b'), sep=newline)
16 GiB
16.00 GiB
mem = 128 Gib
```

classmethod **extract** (*text*, *predefined=None*)

Extract quantities

Takes a string that contains quantity definitions, one per line, and returns those quantities in a dictionary.

Parameters

- **text** (*str*) – The string that contains the quantities, one definition per line. Each is parsed by *assign_rec*. By default, the lines are assumed to be of the form:

```
[<name> [<qname>]] = <value>] [-- <description>]
```

where ‘=’ may be replaced by ‘:’ and ‘-’ may be replaced by ‘//’ or ‘#’. In addition, bracket delimit optional fields and parentheses represent literal parentheses. Each of the fields are allowed to be largely arbitrary strings.

The brackets indicate that the name/value pair and the description is optional. However, <name> must be given if <value> is given.

<name>: the name is used as a key for the value.

<qname>: the name taken by the quantity.

<value>: A number with optional units (ex: 3 or 1pF or 1 kOhm), the units need not be a simple identifier (ex: 9.07 GHz/V).

The value may also be an expression. When giving an expression, you may follow it with a string surrounded by double quotes, which is taken as the units. For example: $T_{stop} = 5/F_{in}$ “s”. The expressions may only contain value defined previously in the same set of definitions, values contained in *predefined*, physical constants, the mathematical constants pi and tau ($2*\pi$), which may be named π or τ , or number literals. The units should not include a scale factor.

When processing the value, it is passed as an argument to *Quantity*, if cannot be converted to a quantity, then it is treated as a Python expression.

<description>: Optional textual description (ex: Frequency of hydrogen line).

Blank lines and any line that does not contain a value are ignored. So with the default *assign_rec*, lines with the following form are ignored:

```
-- comment
# comment
// comment
```

- **predefined** (*dict*) – A dictionary of predefined values. When specified, these values become available to be used in the expressions that give values to the values being defined. You can use *locals()* as this argument to make all local variables available.

Returns a dictionary of quantities for the values specified in the argument.

Return type dict

Example:

```
>>> sagan_frequencies = r'''
...     -- Carl Sagan's SETI frequencies of high interest
...
...     f_hy = 1420.405751786 MHz -- Hydrogen line frequency
...     f_sagan1 = pi*f_hy "Hz" -- Sagan's first frequency
...     f_sagan2 = 2*pi*f_hy "Hz" -- Sagan's second frequency
... '''
>>> freqs = Quantity.extract(sagan_frequencies)
>>> for f in freqs.values():
...     print(f.render(show_label='f'))
f_hy = 1.4204 GHz -- Hydrogen line frequency
f_sagan1 = 4.4623 GHz -- Sagan's first frequency
f_sagan2 = 8.9247 GHz -- Sagan's second frequency

>>> globals().update(freqs)
>>> print(f_hy, f_sagan1, f_sagan2, sep=newline)
1.4204 GHz
4.4623 GHz
8.9247 GHz
```

fixed (*show_units=None, prec=None, show_label=None, show_commas=False, strip_zeros=None, strip_radix=None, scale=None*)
 Convert quantity to fixed-point string.

Parameters

- **show_units** (*bool*) – Whether the units should be included in the string.
- **prec** (*integer or 'full'*) – The desired precision (one plus this value is the desired number of digits). If specified as ‘full’, the full original precision is used.
- **show_label** (*'f', 'a', or bool*) – Add the name and possibly the description when rendering a quantity to a string. Either *label_fmt* or *label_fmt_full* is used to label the quantity.
 - neither is used if *show_label* is False,
 - otherwise *label_fmt* is used if quantity does not have a description or if *show_label* is ‘a’ (short for abbreviated),
 - otherwise *label_fmt_full* is used if *show_desc* is True or *show_label* is ‘f’ (short for full).
- **show_commas** – Add commas to whole part of mantissa, every three digits. If not specified, the global *strip_zeros* setting is used.
- **strip_zeros** (*boolean*) – Remove contiguous zeros from end of fractional part. If not specified, the global *strip_zeros* setting is used.
- **strip_radix** (*boolean*) – Remove radix if there is nothing to the right of it. If not specified, the global *strip_radix* setting is used.
- **scale** (*real, pair, function, or string*) –
 - If a float, it scales the displayed value (the quantity is multiplied by scale before being converted to the string).

- If a tuple, the first value, a float, is treated as a scale factor and the second value, a string, is take to be the units of the displayed value.
- If a function, it takes two arguments, the value and the units of the quantity and it returns two values, the value and units of the displayed value.
- If a string, it is taken to the be desired units. This value along with the units of the quantity are used to select a known unit conversion, which is applied to create the displayed value.

Raises

- **`UnknownConversion(QuantiphyError, KeyError)`** – A unit conversion was requested and there is no corresponding unit converter.
- **`UnknownFormatKey(QuantiphyError, KeyError)`** – ‘label_fmt’ or ‘label_fmt_full’ contains an unknown format key.

Example:

```
>>> t = Quantity('Total = $1000000 -- the total')
>>> print(
...     t.fixed(),
...     t.fixed(show_commas=True),
...     t.fixed(show_units=False), sep=newline)
$1000000
$1,000,000
1000000

>>> print(
...     t.fixed(prec=2, strip_zeros=False, show_commas=True),
...     t.fixed(prec=6),
...     t.fixed(strip_zeros=False, prec=6), sep=newline)
$1,000,000.00
$1000000
$1000000.000000

>>> print(
...     t.fixed(strip_zeros=False, prec='full'),
...     t.fixed(show_label=True),
...     t.fixed(show_label='f'), sep=newline)
$1000000.000000000000
Total = $1000000
Total = $1000000 -- the total

>>> print(
...     t.fixed(scale=(1/10000, 'BTC')),
...     t.fixed(scale=(1/1000, 'ETH')),
...     t.fixed(scale=(1/1000, 'ETH'), show_units=False), sep=newline)
100 BTC
1000 ETH
1000
```

format (*template*="")

Convert quantity to string under the guidance of a template.

Supports the normal floating point and string format types as well some new ones. If the format code is given in upper case, *label_fmt* is used to add the name and perhaps description to the result.

Parameters *template* (*str*) – the format string.

Raises

- **UnknownFormatKey** (*QuantiPhyError*, *KeyError*) – ‘label_fmt’ or ‘label_fmt_full’ contains an unknown format key.
- **UnknownConversion** (*QuantiPhyError*, *KeyError*) – A unit conversion was requested and there is no corresponding unit converter.

The format is specified using A#W,.PTU where:

```
A is a character and gives the alignment: either ' ', '>', '<', or '^'
# is a literal hash that if present indicates that
  trailing zeros and radix should not be suppressed from fractional part.
W is an integer and gives the width of the final string
, is a literal comma, it indicates that the whole part of the
  mantissa should be partitioned into groups of three digits
  separated by commas
.P is a literal period followed by an integer that gives the precision
T is a character and gives the type: choose from p, q, r, s, e, f, g, u, n, ↵
↵d, ...
U is a string that must match a known unit, it invokes scaling
```

Each of these component pieces is optional.

If:

```
q = Quantity('f = 1420.405751786 MHz -- hydrogen line')
```

then:

```
q: quantity [si=y, units=y, label=n] (ex: 1.4204GHz)
Q: quantity [si=y, units=y, label=y] (ex: f = 1.4204GHz)
r: real [si=y, units=n, label=n] (ex: 1.4204G)
R: real [si=y, units=n, label=y] (ex: f = 1.4204G)
  : [label=n] (ex: 1.4204GHz)
p: fixed-point [fixed=y, units=y, label=n] (ex: 1420405751.7860 Hz)
P: fixed-point [fixed=y, units=y, label=y] (ex: f = 1420405751.7860 Hz)
s: string [label=n] (ex: 1.4204GHz)
S: string [label=y] (ex: f = 1.4204GHz)
e: exponential form [si=n, units=n, label=n] (ex: 1.4204e9)
E: exponential form [si=n, units=n, label=y] (ex: f = 1.4204e9)
f: float [label=n] (ex: 1420400000.0000)
F: float [label=y] (ex: f = 1420400000.0000)
g: generalized float [label=n] (ex: 1.4204e+09)
G: generalized float [label=y] (ex: f = 1.4204e+09)
u: units only (ex: Hz)
n: name only (ex: f)
d: description only (ex: hydrogen line)
```

classmethod `get_pref` (*name*)

Get class preference

Returns the value of given preference.

Parameters *name* (*str*) – Name of the desired preference. See `Quantity.set_prefs()` for list of preferences.

Raises *UnknownPreference* (*KeyError*) – unknown preference.

Example:

```

>>> Quantity.set_prefs(known_units='au')
>>> known_units = Quantity.get_pref('known_units')
>>> known_units.append('pc')
>>> Quantity.set_prefs(known_units=known_units)
>>> print(Quantity.get_pref('known_units'))
['au', 'pc']
    
```

is_close (*other*, *reitol*=None, *abstol*=None, *check_units*=True)

Are values equivalent?

Indicates whether the value of a quantity or real number is equivalent to that of a quantity. The two values need not be identical, they just need to be close to be deemed equivalent.

Parameters

- **other** (*quantity or real*) – The value to compare against.
- **reitol** (*float*) – The relative tolerance. If not specified, the *reitol* preference is used, which defaults to 1u.
- **abstol** (*float*) – The absolute tolerance. If not specified, the *abstol* preference is used, which defaults to 1p.
- **check_units** (*bool*) – If True (the default), and if *other* is a quantity, compare the units of the two values, if they differ return False. Otherwise only compare the numeric values, ignoring the units.

Returns Returns true if $\text{abs}(a - b) \leq \max(\text{reitol} * \max(\text{abs}(a), \text{abs}(b)), \text{abstol})$ where *a* and *b* represent *other* and the numeric value of the underlying quantity.

Return type bool

Example:

```

>>> print(
...     c.is_close(c),                # should pass, is identical
...     c.is_close(c+1),             # should pass, is close
...     c.is_close(c+1e4),           # should fail, not close
...     c.is_close(Quantity(c+1, 'm/s')), # should pass, is close
...     c.is_close(Quantity(c+1, 'Hz')), # should fail, wrong units
... )
True True False True False
    
```

is_infinite ()

Test value to determine if quantity is infinite.

Example:

```

>>> inf = Quantity('inf Hz')
>>> inf.is_infinite()
True
    
```

is_nan ()

Test value to determine if quantity is not a number.

Example:

```

>>> nan = Quantity('NaN Hz')
>>> nan.is_nan()
True
    
```

static map_sf_to_greek (*sf*)

Render scale factors in Greek alphabet if appropriate.

Pass this dictionary to *map_sf* preference if you prefer μ rather than u.

Example:

```
>>> with Quantity.prefs(map_sf=Quantity.map_sf_to_greek):
...     print(Quantity('mu0').render(show_label='f'))
 $\mu_0 = 1.2566 \mu\text{H/m}$  -- permeability of free space
```

static map_sf_to_sci_notation (*sf*)

Render scale factors in scientific notation

Pass this function to *map_sf* preference if you prefer your large and small numbers in classic scientific notation. It also causes 'u' to be converted to ' μ '. Set *form* to 'eng' to format all numbers in scientific notation.

Example:

```
>>> with Quantity.prefs(map_sf=Quantity.map_sf_to_sci_notation, show_label='f
↳'):
...     print(
...         Quantity('k').render(),
...         Quantity('mu0').render(),
...         Quantity('mu0').render(form='eng'),
...         sep=newline,
...     )
k = 13.806×1024 J/K -- Boltzmann's constant
 $\mu_0 = 1.2566 \mu\text{H/m}$  -- permeability of free space
 $\mu_0 = 1.2566 \times 10^6 \text{ H/m}$  -- permeability of free space
```

classmethod prefs (**kwargs)

Set class preferences.

This is just like *Quantity.set_prefs()*, except it is designed to work as a context manager, meaning that it is meant to be used with Python's *with* statement. It allows preferences to be set to new values temporarily. They are reset upon exiting the *with* statement. For example:

```
>>> with Quantity.prefs(ignore_sf=True):
...     t = Quantity('600_000 K')
>>> t_bad = Quantity('600_000 K')
>>> print(t, t_bad, sep=newline)
600 kK
600M
```

See *Quantity.set_prefs()* for list of available arguments.

Raises

- **UnknownPreference** (*QuantiPhyError*, **KeyError**) – Unknown preference.
- **UnknownScaleFactor** (*QuantiPhyError*, **ValueError**) – Unknown scale factor.

render (*form=None*, *show_units=None*, *prec=None*, *show_label=None*, *strip_zeros=None*, *strip_radix=None*, *scale=None*)

Convert quantity to a string.

Parameters

- **form** (*str*) – Specifies the form to use for representing numbers by default. Choose from ‘si’, ‘eng’ and ‘fixed’. As an example 0.25 A is represented with 250 mA when form is ‘si’, as 250e-3 A when form is ‘eng’, and with 0.25 A when from is ‘fixed’.
- **show_units** (*bool*) – Whether the units should be included in the string.
- **prec** (*integer or 'full'*) – The desired precision (one plus this value is the desired number of digits). If specified as ‘full’, the full original precision is used.
- **show_label** (*'f', 'a', or boolean*) – Add the name and possibly the description when rendering a quantity to a string. Either *label_fmt* or *label_fmt_full* is used to label the quantity.
 - neither is used if *show_label* is False,
 - otherwise *label_fmt* is used if quantity does not have a description or if *show_label* is ‘a’ (short for abbreviated),
 - otherwise *label_fmt_full* is used if *show_desc* is True or *show_label* is ‘f’ (short for full).
- **strip_zeros** (*boolean*) – Remove contiguous zeros from end of fractional part. If not specified, the global *strip_zeros* setting is used.
- **strip_radix** (*boolean*) – Remove radix if there is nothing to the right of it. If not specified, the global *strip_radix* setting is used.
- **scale** (*real, pair, function, string, or quantity*) –
 - If a float or a quantity, it scales the displayed value (the quantity is multiplied by scale before being converted to the string). If a quantity, the units are ignored.
 - If a tuple, the first value, a float, is treated as a scale factor and the second value, a string, is take to be the units of the displayed value.
 - If a function, it takes two arguments, the value and the units of the quantity and it returns two values, the value and units of the displayed value.
 - If a string, it is taken to the be desired units. This value along with the units of the quantity are used to select a known unit conversion, which is applied to create the displayed value.

Raises

- **UnknownConversion** (*QuantiPhyError, KeyError*) – A unit conversion was requested and there is no corresponding unit converter.
- **UnknownFormatKey** (*QuantiPhyError, KeyError*) – ‘label_fmt’ or ‘label_fmt_full’ contains an unknown format key.

Example:

```

>>> c = Quantity('c')
>>> print(
...     c.render(),
...     c.render(form='si'),
...     c.render(form='eng'),
...     c.render(form='fixed'),
...     c.render(show_units=False),
...     c.render(prec=6),
...     c.render(prec='full'),
...     c.render(show_label=True),
...     c.render(show_label='f'),

```

(continues on next page)

(continued from previous page)

```

...     sep=newline
... )
299.79 Mm/s
299.79 Mm/s
299.79e6 m/s
299792458 m/s
299.79M
299.7925 Mm/s
299.792458 Mm/s
c = 299.79 Mm/s
c = 299.79 Mm/s -- speed of light

>>> print(
...     Tfreeze.render(scale='°F'),
...     Tboil.render(scale='°F'),
...     sep=newline
... )
32 °F
212 °F
    
```

scale (*scale*)

Scale a quantity to create a new quantity.

Parameters *scale* (*real, pair, function, string, or quantity*)–

- If a float, it scales the existing value (a new quantity is returned whose value equals the existing quantity multiplied by scale. In this case the scale is assumed unitless and so the units of the new quantity are the same as those of the existing quantity).
- If a tuple, the first value, a float, is treated as a scale factor and the second value, a string, is taken to be the units of the new quantity.
- If a function, it takes two arguments, the value and the units of the quantity and it returns two values, the value and units of the new value.
- If a string, it is taken to be the desired units. This value along with the units of the quantity are used to select a known unit conversion, which is applied to create the new value.
- If a quantity, the units are ignored and the scale is treated as if were specified as a unitless float.

Raises *UnknownConversion* (*QuantiPhyError, KeyError*) – A unit conversion was requested and there is no corresponding unit converter.

Example:

```

>>> Tf = Tfreeze.scale('°F')
>>> Tb = Tboil.scale('°F')
>>> print(Tf, Tb, sep=newline)
32 °F
212 °F
    
```

classmethod set_prefs (***kwargs*)

Set class preferences.

Any values not passed in are left alone. Pass in *None* to reset a preference to its default value.

Parameters

- **abstol** (*float*) – Absolute tolerance, used by `Quantity.is_close()` when determining equivalence. Default is 10^{12} .
- **assign_rec** (*str*) – Regular expression used to recognize an assignment. Used in constructor and `extract()`. By default an '=' or ':' separates the name from the value and a '-', '#', or '/' separates the value from the description, if a description is given. So the default recognizes the following forms:

```
'vel = 60 m/s'
'vel = 60 m/s -- velocity'
'vel = 60 m/s # velocity'
'vel = 60 m/s // velocity'
'vel: 60 m/s'
'vel: 60 m/s -- velocity'
'vel: 60 m/s # velocity'
'vel: 60 m/s // velocity'
```

The name, value, and description are identified in the regular expression using named groups the names *name*, *val* and *desc*. For example:

```
assign_req = r'(?P<name>.*+) = (?P<val>.*?) -- (?P<desc>.*?)',
```

The regular expression is interpreted using the `re.VERBOSE` flag.

When used with `quantiPHY.Quantity.extract()` there are a few more features.

First, you may also introduce comments using '-', '#', or '/':

```
'-- comment'
'# comment'
'// comment'
```

Second, you can specify an alternate name using by placing in within parentheses following the name:

```
'wavelength ( $\lambda$ ) = 21 cm -- wavelength of hydrogen line'
```

In this case, the name attribute for the quantity will be ' λ ' and the quantity will be filed in the output dictionary using 'wavelength' as the key. If the alternate name is not given, then 'wavelength' is used for the quantity name and dictionary key.

Third, the value may be an expression involving the previously specified values. When doing so, you can specify the units by following the value expression with a double-quoted string. The expressions may contain numeric literals, previously defined quantities, and the constants pi and tau. For example:

```
parameters = Quantity.extract(r'''
    Fin = 250MHz -- frequency of input stimulus
    Tstop = 10/Fin "s" -- simulation stop time
''')
```

In this example, the value for *Tstop* is given as an expression involving *Fin*.

- **form** (*str*) – Specifies the form to use for representing numbers by default. Choose from 'si', 'eng' and 'fixed'. As an example 0.25 A is represented with 250 mA when form is 'si', as 250e-3 A when form is 'eng', and with 0.25 A when from is 'fixed'.
- **full_prec** (*int*) – Default full precision in digits where 0 corresponds to 1 digit. Must be nonnegative. This precision is used when the full precision is requested and the precision is not otherwise known. Default is 12.

- **ignore_sf** (*bool*) – Whether all scale factors should be ignored by default when recognizing numbers.
- **input_sf** (*str*) – Which scale factors to recognize when reading numbers. The default is ‘YZEPTGMKk_cmuμnpfazy’. You can use this to ignore the scale factors you never expect to reduce the chance of a scale factor/unit ambiguity. For example, if you expect to encounter temperatures in Kelvin and can do without ‘K’ as a scale factor, you might use ‘TGMK_munpfa’. This also gets rid of the unusual scale factors.
- **keep_components** (*bool*) – Indicate whether components should be kept if quantity value was given as string. Doing so takes a bit of space, but allows the original precision of the number to be recreated when full precision is requested.
- **known_units** (*list or string*) – List of units that are expected to be used in preference to a scale factor when the leading character could be mistaken as a scale factor. If a string is given, it is split at white space to form the list. When set, any previous known units are overridden.
- **label_fmt** (*str*) – Format string used when label is requested if the quantity does not have a description or if the description was not requested (if *show_desc* is False). Is passed through string .format() method. Format string takes two possible arguments named *n* and *v* for the name and value. A typical values include:

```
'{n} = {v}'      (default)
'{n}: {v}'
```

- **label_fmt_full** (*str*) – Format string used when label is requested if the quantity has a description and the description was requested (if *show_desc* is True). Is passed through string .format() method. Format string takes four possible arguments named *n*, *v*, *d* and *V* for the name, value, description, and value as formatted by *label_fmt*. Typical value include:

```
'{n} = {v} -- {d}'      (default)
'{n} = {v} # {d}'
'{n} = {v} // {d}'
'{n}: {v} -- {d}'
'{V} -- {d}'
'{V:<20} # {d}'
```

The last example shows the *V* argument with alignment and width modifiers. In this case the modifiers apply to the name and value after being they are combined with the *label_fmt*. This is typically done when printing several quantities, one per line, because it allows you to line up the descriptions.

- **map_sf** (*dictionary or function*) – Use this to change the way individual scale factors are rendered, ex: `map_sf={'u': 'μ'}` to render micro using mu. If a function is given, it takes a single string argument, the nominal scale factor (which would be the exponent if no scale factor fits), and returns either a string or a tuple. The string is the desired scale factor. The tuple consists of the string and a flag. If the flag is True the string is treated as an exponent, otherwise it is treated as a scale factors. The difference between an exponent and a scale factor is that the spacer goes after an exponent and before a scale factor. *QuantiPhy* provides two predefined functions intended for use with *maps_sf*: *Quantity.map_sf_to_greek()* and *Quantity.map_sf_to_sci_notation()*.
- **number_fmt** (*dictionary or function*) – Format string used to convert the components of the number into the number itself. Normally this is not necessary. However, it can be used to perform special formatting that is helpful when aligning numbers in

tables. It allows you to specify the widths and alignments of the individual components. There are three named components: *whole*, *frac*, and *units*. *whole* contains the portion of the mantissa to the left of the radix (decimal point). It is the whole mantissa if there is no radix. It also includes the sign and the leading units (currency symbols), if any. *frac* contains the radix and the fractional part. It also contains the exponent if the number has one. *units* contains the scale factor and units. The following value can be used to align both the radix and the units, and give the number a fixed width:

```
number_fmt = '{whole:>3s}{frac:<4s} {units:<3s}'
```

The various widths and alignments could be adjusted to fit a variety of needs.

It is also possible to specify a function as *number_fmt*, in which case it is passed the three values in order (*whole*, *frac* and *units*) and is expected to return the number as a string.

- **output_sf** (*str*) – Which scale factors to output, generally one would only use familiar scale factors. The default is ‘TGMkmunpfa’, which gets rid of the very large (‘YZEP’) and very small (‘zy’) scale factors that many people do not recognize.
- **prec** (*int*) – Default precision in digits where 0 corresponds to 1 digit. Must be non-negative. This precision is used when the full precision is not required. Default is 4.
- **reltol** (*float*) – Relative tolerance, used by *Quantity.is_close()* when determining equivalence. Default is 10⁶.
- **show_commas** (*bool*) – When rendering to fixed-point string, add commas to the whole part of the mantissa, every three digits. By default this is False.
- **show_desc** (*bool*) – Whether the description should be shown if it is available when showing the label. By default *show_desc* is False.

Deprecated since version 2.1: Use *show_label='f'* instead.

- **show_label** (*'f', 'a', or bool*) – Add the name and possibly the description when rendering a quantity to a string. Either *label_fmt* or *label_fmt_full* is used to label the quantity.
 - Neither is used if *show_label* is False,
 - otherwise *label_fmt* is used if quantity does not have a description or if *show_label* is ‘a’ (short for abbreviated),
 - otherwise *label_fmt_full* is used if *show_desc* is True or *show_label* is ‘f’ (short for full).
- **spacer** (*str*) – The spacer text to be inserted in a string between the numeric value and the scale factor when units are present. Is generally specified to be ‘ ’ or ‘ ‘; use the latter if you prefer a space between the number and the units. Generally using ‘ ‘ makes numbers easier to read, particularly with complex units, and using ‘ ’ is easier to parse. You could also use a Unicode non-breaking space ‘ ’. For your convenience, you can access a non-breaking space using *Quantity.non_breaking_space*.
- **strip_radix** (*bool*) – When rendering, strip the radix (decimal point) if not needed from numbers even if they could then be mistaken for integers. If this setting is False, the radix is still striped if the number has a scale factor. By default this is True.

Set *strip_radix* to False when generating output that will be read by a parser that distinguishes between integers and reals based on the presence of a decimal point.
- **strip_zeros** (*bool*) – When rendering, strip off any unneeded zeros from the number. By default this is True.

Set `strip_zeros` to `False` when you would like to indicated the precision of your numbers based on the number of digits shown.

- **`unity_sf`** (*str*) – The output scale factor for unity, generally ‘’ or ‘_’. The default is ‘’, but use ‘_’ if you want there to be no ambiguity between units and scale factors. For example, 0.3 would be rendered as ‘300m’, and 300 m would be rendered as ‘300_m’.

Raises

- **`UnknownPreference`** (`QuantiPhyError`, `KeyError`) – Unknown preference.
- **`UnknownScaleFactor`** (`QuantiPhyError`, `ValueError`) – Unknown scale factor.

Example:

```
>>> mu0 = Quantity('mu0')
>>> print(mu0)
1.2566 uH/m

>>> Quantity.set_prefs(prec=6, map_sf={'u': '\u03bc'})
>>> print(mu0)
1.256637 \u03bcH/m

>>> Quantity.set_prefs(prec=None, map_sf=None)
>>> print(mu0)
1.2566 uH/m
```

6.2.2 Unit Conversion

class `quantiphy.UnitConversion` (*to_units, from_units, slope=1, intercept=0*)

Creates a unit converter. Just the creation of the converter is sufficient to make it available to `Quantity` (the `UnitConversion` object itself is normally discarded). Once created, it is automatically employed by `Quantity` when a conversion is requested with the given units. A forward conversion is performed if the from and to units match, and a reversion conversion is performed if they are swapped. A no-op conversion is performed when converting one from- unit to another or one to-unit to another.

Parameters

- **`to_units`** (*string or list of strings*) – A collection of units. If given as a single string it is split.
- **`from_units`** (*string or list of strings*) – A collection of units. If given as a single string it is split.
- **`slope`** (*float*) – Scale factor for conversion. You may also pass a function as an argument, in which case it is treated is used to perform forward conversions. In this case, *intercept* should also be passed a callable.
- **`intercept`** (*float*) – Conversion offset. You may also pass a function as an argument, in which case it is treated is used to perform reverse conversions. In this case, *slope* should also be passed a callable.

Forward Conversion: The following conversion is applied if the given units are among the *from_units* and the desired units are among the *to_units*:

$$\text{new_value} = \text{given_value} * \text{slope} + \text{intercept}$$

Or, if *slope* is callable:

$$\text{new_value} = \text{slope}(\text{given_value})$$

In this case the name *slope* is misleading.

Reverse Conversion: The following conversion is applied if the given units are among the *to_units* and the desired units are among the *from_units*:

$$\text{new_value} = (\text{given_value} - \text{intercept})/\text{slope}$$

Or, if *intercept* is callable:

$$\text{new_value} = \text{intercept}(\text{given_value})$$

In this case the name *intercept* is misleading.

No-Op Conversion: The following conversion is applied if the given and desired units are both found among the from-units or are both found among the to-units.

$$\text{new_value} = \text{given_value}$$

Example:

```
>>> from quantiphy import Quantity, UnitConversion
>>> m2pc = UnitConversion('m', 'pc parsec', 3.0857e16)
```

Normally one simply discards the return value of `UnitConversion`, but if kept you can convert it to a string to get a summary of the conversion:

```
>>> print(str(m2pc))
m = 3.0857e+16*pc
```

The act of creating this unit conversion establishes a conversion between meters (m) and parsecs (parsec, pc) that is accessible when creating or rendering quantities and can go both ways:

```
>>> d_sol = Quantity('5 μpc', scale='m') # forward conversion
>>> print(d_sol)
154.28 Gm

>>> d_ac = Quantity(1.339848, units='pc') # reverse conversion
>>> print(d_ac.render(scale='m'))
41.344e15 m

>>> d_ac = Quantity(1.339848, units='pc') # no-op conversion
>>> print(f'{d_ac:qparsec}')
1.3398 parsec
```

The conversion can employ both a slope and an intercept, and if you convert the converter object to a string, it summarizes the conversion, which can help you avoid mistakes:

```
>>> conversion = UnitConversion('F', 'C', 1.8, 32)
>>> print(str(conversion))
F = 1.8*C + 32
```

You can also use functions to perform the conversions, which is appropriate when the conversion is nonlinear (cannot be described with a slope and intercept). For example:

```
>>> from quantiphy import UnitConversion, Quantity
>>> from math import log10

>>> def from_dB(value):
...     return 10**(value/20)
```

(continues on next page)

(continued from previous page)

```

>>> def to_dB(value):
...     return 20*log10(value)

>>> converter = UnitConversion('V', 'dBV', from_dB, to_dB)
>>> converter = UnitConversion('A', 'dBA', from_dB, to_dB)

>>> print('{:pdBV}, {:pdBV}'.format(Quantity('100mV'), Quantity('10V')))
-20 dBV, 20 dBV

>>> print('{:qV}, {:qV}'.format(Quantity('-20 dBV'), Quantity('20 dBV')))
100 mV, 10 V

>>> print('{:pdBA}, {:pdBA}'.format(Quantity('100mA'), Quantity('10A')))
-20 dBA, 20 dBA

>>> print('{:qA}, {:qA}'.format(Quantity('-20 dBA'), Quantity('20 dBA')))
100 mA, 10 A
    
```

convert (*value=1, from_units=None, to_units=None*)

Convert value to quantity with new units.

A convenience method. Normally it is not needed because once created, a unit conversion becomes directly accessible to quantities and can be used both when creating or rendering the quantity.

Parameters

- **value** – The value to convert. May be a real number or a quantity. Alternately, may simply be a string, in which case it is taken to be the `from_units`. If the value is not given it is taken to be 1.
- **from_units** (*str*) – The units to convert from. If not given, the class's first `from_units` are used.
- **to_units** (*str*) – The units to convert to. If not given, the class's first `to_units` are used.

If the `from_units` were found among the class's `from_units`, and the `to_units` were found among the class's `to_units`, then a forward conversion is performed.

If the `from_units` were found among the class's `to_units`, and the `to_units` were found among the class's `from_units`, then a reverse conversion is performed.

Raises *UnknownConversion* (*QuantiPhyError*, *KeyError*) – The given units are not supported by the underlying class.

Example:

```

>>> m = m2pc.convert()
>>> print(str(m))
30.857e15 m

>>> pc = m2pc.convert(m)
>>> print(str(pc))
1 pc

>>> m = m2pc.convert(pc)
>>> print(str(m))
30.857e15 m

>>> m2pc.convert(30.857e15, 'm')
    
```

(continues on next page)

(continued from previous page)

```
Quantity('1 pc')

>>> m2pc.convert(1000, 'pc')
Quantity('30.857e18 m')

>>> m2pc.convert('pc')
Quantity('30.857e15 m')
```

6.2.3 Constants and Unit Systems

`quantiphy.add_constant` (*value*, *alias=None*, *unit_systems=None*)

Saves a quantity in such a way that it can later be recalled by name when creating new quantities.

Parameters

- **value** (*quantity*) – The value of the constant. Must be a quantity or a string that can be directly converted to a quantity.
- **alias** (*str*) – An alias for the constant. Can be used to access the constant from as an alternative to the name given in the value, which itself is optional. If the value has a name, specifying this name is optional. If both are given, the constant is accessible using either name. *alias* may also be a list of aliases.
- **unit_systems** (*list or str*) – Name or names of the unit systems to which the constant should be added. If given as a string, string will be split at white space to create the list. If a constant is associated with a unit system, it is only available when that unit system is active. You need not limit yourself to the predefined ‘mks’ and ‘cgs’ unit systems. Giving a name creates the corresponding unit system if it does not already exist. If *unit_systems* is not given, the constant is not associated with a unit system, meaning that it is always available regardless of which unit system is active.

Raises

- **ExpectedQuantity** (**QuantiPhyError**, **ValueError**) – *value* must be an instance of `quantiphy.Quantity` or it must be a string that can be converted to a quantity.
- **MissingName** (**QuantiPhyError**, **NameError**) – *alias* was not specified and no name was available from *value*.

The constant is saved under *name* if given, and under the name contained within *value* if available. It is not necessary to supply both names, one is sufficient.

Example:

```
>>> from quantiphy import Quantity, add_constant
>>> add_constant('f_hy = 1420.405751786 MHz -- Frequency of hydrogen line')
>>> print(Quantity('f_hy').render(show_label='f'))
f_hy = 1.4204 GHz -- Frequency of hydrogen line
```

`quantiphy.set_unit_system` (*unit_system*)

Activates a unit system.

The default unit system is ‘mks’. Calling this function changes the active unit system to the one with the specified name. Only constants associated with the active unit system or not associated with a unit system are available for use.

Parameters `unit_system` (*str*) – Name of the desired unit system.

Raises `UnknownUnitSystem(QuantiphyError, KeyError)` – `unit_system` does not correspond to a known unit system.

Example:

```
>>> from quantiphy import Quantity, set_unit_system
>>> set_unit_system('cgs')
>>> print(Quantity('h').render(show_label='f'))
h = 6.6261e-27 erg-s -- Plank's constant

>>> set_unit_system('mks')
>>> print(Quantity('h').render(show_label='f'))
h = 662.61e-36 J-s -- Plank's constant
```

6.2.4 Exceptions

class `quantiphy.QuantiPhyError`
 QuantiPhy base exception.

All of the specific QuantiPhy exceptions subclass this exception.

class `quantiphy.ExpectedQuantity(*args)`
 The value is required to be a Quantity or a string that can be converted to a Quantity.

class `quantiphy.IncompatibleUnits(*args)`
 The units of the contribution do not match those of the underlying quantity.

class `quantiphy.InvalidNumber(*args)`
 The value given could not be converted to a number.

class `quantiphy.InvalidRecognizer(*args)`
 The `assign_rec` preference is expected to be a regular expression that defines one or more named fields, one of which must be `val`. This exception is raised when the current value of `assign_rec` does not satisfy this requirement.

class `quantiphy.MissingName(*args)`
alias was not specified and no name was available from *value*.

class `quantiphy.UnknownConversion(*args, **kwargs)`
 The given units are not supported by the underlying class, or a unit conversion was requested and there is no corresponding unit converter.

class `quantiphy.UnknownFormatKey(*args)`
 The `label_fmt` and `label_fmt_full` are expected to be format strings that may interpolate certain named arguments. The valid named arguments are *n* for name, *v* for value, and *d* for description. This exception is raised when some other name is used for an interpolated argument.

class `quantiphy.UnknownPreference(*args)`
 The name given for a preference is unknown.

class `quantiphy.UnknownScaleFactor(*args)`
 The `input_sf` preference gives the list of scale factors that should be accepted. This exception is raised if `input_sf` contains an unknown scale factor.

class `quantiphy.UnknownUnitSystem(*args)`
 The name given does not correspond to a known unit system.

6.3 Examples

6.3.1 Motivating Example

QuantiPhy is a light-weight package that allows numbers to be combined with units into quantities. Quantities are very commonly encountered when working with real-world systems when numbers are involved. And when encountered, the numbers often use SI scale factors to make them easier to read and write. Surprisingly, most computer languages do not support numbers in this form. This is even more surprising when you realize that this form is a very well established international standard and has been for more than 50 years.

When working with quantities, one often has to choose between using a form that is easy for computers to read or one that is easy for humans to read. For example, consider this table of critical frequencies needed in jitter tolerance measurements in optical communication:

```
>>> table1 = """
...     SDH      | Rate          | f1      | f2      | f3      | f4
...     -----+-----+-----+-----+-----+-----
...     STM-1   | 155.52 Mb/s  | 500 Hz  | 6.5 kHz | 65 kHz  | 1.3 MHz
...     STM-4   | 622.08 Mb/s  | 1 kHz   | 25 kHz  | 250 kHz | 5 MHz
...     STM-16  | 2.48832 Gb/s | 5 kHz   | 100 kHz | 1 MHz   | 20 MHz
...     STM-64  | 9.95328 Gb/s | 20 kHz  | 400 kHz | 4 MHz   | 80 MHz
...     STM-256 | 39.81312 Gb/s | 80 kHz  | 1.92 MHz | 16 MHz  | 320 MHz
...     """
```

This table was formatted to be easily read by humans. If it were formatted for computers, the numbers would be given without units and in exponential notation because they have dramatically different sizes. For example, it might look like this:

```
>>> table2 = """
...     SDH      | Rate (b/s)    | f1 (Hz) | f2 (Hz) | f3 (Hz) | f4 (Hz)
...     -----+-----+-----+-----+-----+-----
...     STM-1   | 1.5552e8     | 5e2     | 6.5e3   | 6.5e3   | 1.3e6
...     STM-4   | 6.2208e8     | 1e3     | 2.5e3   | 2.5e5   | 5e6
...     STM-16  | 2.48832e9    | 5e3     | 1e5     | 1e6     | 2e7
...     STM-64  | 9.95328e9    | 2e4     | 4e5     | 4e6     | 8e7
...     STM-256 | 3.981312e10  | 8e4     | 1.92e6  | 1.6e7   | 3.2e8
...     """
```

This contains the same information, but it is much harder for humans to read and interpret. Often the compromise of partially scaling the numbers can be used to make the table easier to interpret:

```
>>> table3 = """
...     SDH      | Rate (Mb/s)   | f1 (kHz) | f2 (kHz) | f3 (kHz) | f4 (MHz)
...     -----+-----+-----+-----+-----+-----
...     STM-1   | 155.52        | 0.5      | 6.5      | 65       | 1.3
...     STM-4   | 622.08        | 1         | 2.5      | 250      | 5
...     STM-16  | 2488.32       | 5         | 100      | 1000     | 20
...     STM-64  | 9953.28       | 20        | 400      | 4000     | 80
...     STM-256 | 39813.12      | 80        | 1920     | 16000    | 320
...     """
```

This looks cleaner, but it involves perhaps even more effort to interpret because the values are distant from their corresponding scaling and units, because the large and small values are oddly scaled (0.5 kHz is more naturally given as 500Hz and 39813 MHz is more naturally given as 39.8 GHz), and because each column may have a different scaling factor. While these might seem like minor inconveniences on this table, they can become quite annoying as tables become larger or more numerous. This problem exists with both tables and graphs. Fundamentally the issue is

that your eyes are naturally drawn to the number, but the numbers are not complete. Your eyes need to hunt further and it is not obvious where to hunt. If not next to the number, the scaling and units for the numbers may be found in the column headings, the axes, the labels, the title, the caption, or in the body of the text. The sheer number of places to look can dramatically slow the interpretation of the data. This problem does not exist in the first table where each number is complete as it includes both its scaling and its units. The eye gets the full picture on the first glance.

This last version of the table represents a very common mistake people make when presenting data. They feel that adding units and scale factors to each number adds clutter and wastes space and so removes them from the data and places them somewhere else. Doing so results in a data that perhaps is visually cleaner but is harder for the reader to interpret. All these tables contain the same information, but in the second two tables the readability has been traded off in order to make the data easier to read into a computer because in most languages there is no easy way to read numbers that have either units or scale factors.

QuantiPhy makes it easy to read and generate numbers with units and scale factors so you do not have to choose between human and computer readability. For example, the above tables could be read with the following code (it must be tweaked somewhat to handle tables 2 and 3):

```
>>> from quantiphy import Quantity

>>> # parse the table
>>> sdh = []
>>> lines = table1.strip().split('\n')
>>> for line in lines[2:]:
...     fields = line.split('|')
...     name = fields[0].strip()
...     rate = Quantity(fields[1])
...     critical_freqs = [Quantity(f) for f in fields[2:]]
...     sdh.append((name, rate, critical_freqs))

>>> # print the table in a form suitable for humans
>>> for name, rate, freqs in sdh:
...     print('{:8s}: {:12q} {:9q} {:9q} {:9q}'.format(name, rate, *freqs))
STM-1   : 155.52 Mb/s    500 Hz    6.5 kHz    65 kHz    1.3 MHz
STM-4   : 622.08 Mb/s    1 kHz     25 kHz    250 kHz    5 MHz
STM-16  : 2.4883 Gb/s     5 kHz    100 kHz    1 MHz     20 MHz
STM-64  : 9.9533 Gb/s    20 kHz   400 kHz    4 MHz     80 MHz
STM-256 : 39.813 Gb/s     80 kHz   1.92 MHz   16 MHz    320 MHz

>>> # print the table in a form suitable for machines
>>> for name, rate, freqs in sdh:
...     print('{:8s}: {:12.4e} {:9.2e} {:9.2e} {:9.2e} {:9.2e}'.format(name, rate,
↳*(1*f for f in freqs)))
STM-1   : 1.5552e+08  5.00e+02  6.50e+03  6.50e+04  1.30e+06
STM-4   : 6.2208e+08  1.00e+03  2.50e+04  2.50e+05  5.00e+06
STM-16  : 2.4883e+09  5.00e+03  1.00e+05  1.00e+06  2.00e+07
STM-64  : 9.9533e+09  2.00e+04  4.00e+05  4.00e+06  8.00e+07
STM-256 : 3.9813e+10  8.00e+04  1.92e+06  1.60e+07  3.20e+08

>>> # print the table in a compromise form
>>> for name, rate, freqs in sdh:
...     print(
...         '{:8s}: {:12.2f} {:9.1f} {:9.1f} {:9.1f} {:9.1f}'.format(
...             name, rate.scale(1e-6), freqs[0].scale(1e-3),
...             freqs[1].scale(1e-3), freqs[2].scale(1e-3), freqs[3].scale(1e-6)
...         )
...     )
STM-1   : 155.52      0.5      6.5      65      1.3
STM-4   : 622.08      1        25      250     5
```

(continues on next page)

(continued from previous page)

STM-16	:	2488.32	5	100	1000	20
STM-64	:	9953.28	20	400	4000	80
STM-256	:	39813.12	80	1920	16000	320

The code reads the data and then produces three outputs. The first output shows that quantities can be displayed in easily readable forms with their units (approximates table1). The second output shows that the values are easily accessible for computation (approximates table2). The use of `1*f` is not necessary to be able to see the results in exponential notation, rather it is there to demonstrate that it is easy to do calculations on Quantities. Finally, the third output represents a compromise between being human and machine readable (approximates table3).

`quantiphy.Quantity` is used to convert a number string, such as '155.52 Mb/s' into an internal representation that includes the value and the units: `155.52e6` and 'b/s'. The scaling factor is properly interpreted. Once a value is converted to a *Quantity*, it can be treated just like a normal *float*. The main difference occurs when it is time to convert it back to a string. When doing so, the scale factor and units are included by default.

6.3.2 DRAM Prices

Here is a table that was found on the Internet that gives the number of bits of dynamic RAM a dollar would purchase over time:

```
>>> bits_per_dollar = '''
... 1973 490
... 1978 2780
... 1983 16400
... 1988 91800
... 1993 368000
... 1998 4900000
... 2003 26300000
... 2008 143000000
... 2013 833000000
... 2018 5000000000
... '''
```

It is pretty easy to read in the early years, but by the turn of the millennium you have to start counting the zeros by hand to understand the number. And are those bits or bytes? Reformatting with *QuantiPhy* makes it much more readable:

```
>>> for line in bits_per_dollar.strip().split('\n'):
...     year, bits = line.split()
...     bits = Quantity(bits, 'b')
...     print(f'{year} {bits:11q} {bits:11qB}')
1973      490 b      61.25 B
1978     2.78 kb     347.5 B
1983    16.4 kb     2.05 kB
1988   91.8 kb    11.475 kB
1993   368 kb     46 kB
1998   4.9 Mb     612.5 kB
2003  26.3 Mb    3.2875 MB
2008  143 Mb    17.875 MB
2013  833 Mb   104.12 MB
2018    5 Gb     625 MB
```

Notice that *bits* was printed twice. The first time the formatting code included a width specification, but in the second the desired unit of measure was specified (*B*), which caused the underlying value to be converted from bits to bytes.

It is important to recognize that *QuantiPhy* is using decimal rather than binary scale factors. So 5 GB is 5 gigabyte and not 5 gibibyte. In other words 5 GB represents 5×10^9 B and not 5×2^{30} B. This table can be reformulated to use

the binary scale factors by changing the *q* format characters to *b*:

```
>>> for line in bits_per_dollar.strip().split('\n'):
...     year, bits = line.split()
...     bits = Quantity(bits, 'b')
...     print(f'{year}  {bits:11b}  {bits:11bB}')
1973      490 b          61.25 B
1978  2.7148 Kib        347.5 B
1983  16.016 Kib        2.002 KiB
1988  89.648 Kib        11.206 KiB
1993  359.38 Kib        44.922 KiB
1998   4.673 Mib        598.14 KiB
2003  25.082 Mib        3.1352 MiB
2008  136.38 Mib        17.047 MiB
2013  794.41 Mib        99.301 MiB
2018   4.6566 Gib        596.05 MiB
```

6.3.3 Thermal Voltage Example

In this example, quantities are used to represent all of the values used to compute the thermal voltage: $V_t = kT/q$. It is not terribly useful, but does demonstrate several of the features of *QuantiPhy*.

```
>>> from quantiphy import Quantity
>>> with Quantity.prefs(
...     show_label = 'f',
...     label_fmt = '{n} = {v}',
...     label_fmt_full = '{V:<18} # {d}',
... ):
...     T = Quantity(300, 'T K ambient temperature')
...     k = Quantity('k')
...     q = Quantity('q')
...     Vt = Quantity(k*T/q, f'Vt V thermal voltage at {T:q}')
...     print(T, k, q, Vt, sep='\n')
T = 300 K          # ambient temperature
k = 13.806e-24 J/K # Boltzmann's constant
q = 160.22e-21 C   # elementary charge
Vt = 25.852 mV     # thermal voltage at 300 K
```

The first part of this example imports *quantiphy.Quantity* and sets the *show_label*, *label_fmt* and *label_fmt_full* preferences to display both the value and the description by default. *label_fmt* is used when the description is not present and *label_fmt_full* is used when it is present. In *label_fmt* the {n} is replaced by the *name* and {v} is replaced by the value (numeric value and units). In *label_fmt_full*, the {V:<18} is replaced by the expansion of *label_fmt*, left justified with a field width of 18, and the {d} is replaced by the description.

The second part defines four quantities. The first is given in a very specific way to avoid the ambiguity between units and scale factors. In this case, the temperature is given in Kelvin (K), and normally if the temperature were given as the string '300 K', the units would be confused for the scale factor. As mentioned in *Ambiguity of Scale Factors and Units* the 'K' would be treated as a scale factor unless you took explicit steps. In this case, this issue is circumvented by specifying the units in the *model* along with the name and description. The *model* is also used when creating *Vt* to specify the name, units, and description.

The last part simply prints the four values. The *show_label* preference is set so that names and descriptions are printed along with the values. In this case, since all the quantities have descriptions, *label_fmt_full* is used to format the output.

6.3.4 Casual Time Units

This example shows how one could allow users to enter time durations using a variety of casual units of time. *QuantiPhy* only pre-defines conversions for time units that are unambiguous and commonly used in scientific computation, so that leaves out units like months and years. However, in many situations the goal is simplicity rather than precision. In such a situation, it is convenient to support any units a user may reasonable expect to use. In a casual setting it would be very unusual to use SI scale factors, so there use will be prohibited to allow a greater range of units (ex. m for minutes).

This example assumes that a collection of time duration values are contained in a configuration file, in this example represented by *configuration*. Normally these values would be contained in a separate file that is opened and read, but for the sake of simplicity in the example, the ‘contents’ of the file is just given as a multiline string. The user can give the durations using any units they like, but internally they are all converted to seconds.

```
>>> from quantiphy import Quantity, UnitConversion
>>> _ = UnitConversion('s', 'sec second seconds')
>>> _ = UnitConversion('s', 'm min minute minutes', 60)
>>> _ = UnitConversion('s', 'h hr hour hours', 60*60)
>>> _ = UnitConversion('s', 'd day days', 24*60*60)
>>> _ = UnitConversion('s', 'w week weeks', 7*24*60*60)
>>> _ = UnitConversion('s', 'M month months', 30*24*60*60)
>>> _ = UnitConversion('s', 'y year years', 365*24*60*60)
>>> Quantity.set_prefs(ignore_sf=True)

>>> configuration = '''
...     time_to_live = 3 months
...     time_limit = 1 day
...     time_out = 10m
... '''
>>> limits = Quantity.extract(configuration)

>>> for k, v in limits.items():
...     print(f'{k} = {v:ps}')
time_to_live = 7776000 s
time_limit = 86400 s
time_out = 600 s
```

Notice that the return values from *UnitConversion* are captured in a variable (`_`) in the code above. This is not necessary. It is done in this case to satisfy the testing framework that tests the code found in this documentation; normally the return value is discarded.

6.3.5 Unicode Text Example

In this example *QuantiPhy* formats quantities to be embedded in text. To make the text as clean as possible, *QuantiPhy* is configured to use Unicode scale factors and the Unicode non-breaking space as the spacer. The non-breaking space prevents units from being placed on a separate line from their number, making the quantity easier to read.

```
>>> from quantiphy import Quantity
>>> import textwrap

>>> Quantity.set_prefs(
...     map_sf = Quantity.map_sf_to_sci_notation,
...     spacer = Quantity.non_breaking_space
... )

>>> constants = [
```

(continues on next page)

(continued from previous page)

```

...     Quantity('h'),
...     Quantity('hbar'),
...     Quantity('k'),
...     Quantity('q'),
...     Quantity('c'),
...     Quantity('0C'),
...     Quantity('eps0'),
...     Quantity('mu0'),
... ]

>>> # generate some sentences that contain quantities
>>> sentences = [f'{q.desc.capitalize()} is {q}.' for q in constants]

>>> # combine the sentences into a left justified paragraph
>>> print(textwrap.fill(' '.join(sentences)))
Plank's constant is 662.61×1036 J-s. Reduced plank's constant is
105.46×1036 J-s. Boltzmann's constant is 13.806×1024 J/K.
Elementary charge is 160.22×1021 C. Speed of light is 299.79 Mm/s.
Zero degrees celsius in kelvin is 273.15 K. Permittivity of free
space is 8.8542 pF/m. Permeability of free space is 1.2566 μH/m.
    
```

When rendered in your browser with a variable width font, the result looks like this:

Plank's constant is 662.61×10³⁶ J-s. Reduced plank's constant is 105.46×10³⁶ J-s. Boltzmann's constant is 13.806×10²⁴ J/K. Elementary charge is 160.22×10²¹ C. Speed of light is 299.79 Mm/s. Zero degrees Celsius in Kelvin is 273.15 K. Permittivity of free space is 8.8542 pF/m. Permeability of free space is 1.2566 μH/m.

6.3.6 Timeit Example

A Python module that benefits from *QuantiPhy* is *timeit*, a package in the standard library that runs a code snippet a number of times and prints the elapsed time for the test. However, from a usability perspective it has several issues. First, it prints out the elapsed time of all the repetitions rather than dividing the elapsed time by the number of repetitions and reporting the average time per operation. So it can quickly allow you to compare the relative speed of various operations, but it does not directly give you a sense of the time required in absolute terms. Second, it does not label its output, so it is not clear what is being displayed. Here is an example where *timeit* has been fortified with *QuantiPhy* to make the output more readable. To make it more interesting, the timing results are run on *QuantiPhy* itself. The results give you a feel for how much slower *QuantiPhy* is to both convert strings to quantities and quantities to strings compared into the built-in float class.

```

#!/usr/bin/env python3
from timeit import timeit
from random import random, randint
from quantiphy import Quantity

# preferences
trials = 100_000
Quantity.set_prefs(
    prec = 2,
    show_label = True,
    label_fmt = '{n:>40}: {v}',
    map_sf = Quantity.map_sf_to_greek
)

# build the raw data, arrays of random numbers
    
```

(continues on next page)

(continued from previous page)

```
s_numbers = []
s_quantities = []
numbers = []
quantities = []
for i in range(trials):
    mantissa = 20*random()-10
    exponent = randint(-35, 35)
    number = '%0.25fe%s' % (mantissa, exponent)
    quantity = number + ' Hz'
    s_numbers.append(number)
    s_quantities.append(quantity)
    numbers.append(float(number))
    quantities.append(Quantity(number, 'Hz'))

# define testcases
testcases = [
    '[float(v) for v in s_numbers]',
    '[Quantity(v) for v in s_quantities]',
    '[str(v) for v in numbers]',
    '[str(v) for v in quantities]',
]

# run testcases and print results
print(f'For {Quantity(trials)} values ...')
for case in testcases:
    elapsed = timeit(case, number=1, globals=globals())
    result = Quantity(elapsed/trials, units='s/op', name=case)
    print(result)
```

The results are:

```
For 100k iterations ...
    [float(v) for v in s_numbers]: 638 ns/op
    [Quantity(v) for v in s_quantities]: 15.3 µs/op
    [str(v) for v in numbers]: 1.03 µs/op
    [str(v) for v in quantities]: 28.1 µs/op
```

You can see that *QuantiPhy* is considerably slower than the float class, which you should be aware of if you are processing large quantities of numbers.

Contrast this with the normal output from *timeit*:

```
0.05213119700783864
1.574107409993303
0.10471829099697061
2.3749650190002285
```

The essential information is there, but it takes longer to make sense of it.

6.3.7 Disk Usage Example

Here is a simple example that uses *QuantiPhy* to clean up the output from the Linux disk usage utility. It runs the *du* command, which prints out the disk usage of files and directories. The results from *du* are gathered and then sorted by size and then the size and name of each item is printed.

Quantity is used to scale the filesize reported by *du* from KB to B. Then the list of files is sorted by size. Here we are

exploiting the fact that quantities act like floats, and so the sorting can be done with no extra effort. Finally, the ability to render to a number with a scale factor and units is used when presenting the results.

```
#!/usr/bin/env python3
# runs du and sorts the output while suppressing any error messages from du

from quantiphy import Quantity
from inform import display, fatal, os_error
from shlib import Run
import sys

try:
    du = Run(['du'] + sys.argv[1:], modes='WEO1')

    files = []
    for line in du.stdout.split('\n'):
        if line:
            size, filename = line.split('\t', 1)
            files += [(Quantity(size, scale=(1024, 'B')), filename)]

    files.sort(key=lambda x: x[0])

    for size, name in files:
        display('{:7.2b} {}'.format(size, name))

except OSError as err:
    fatal(os_error(err))
except KeyboardInterrupt:
    display('dus: killed by user.')
```

And here is an example of the programs output:

```
460 kB  quantiphy/examples/delta-sigma
464 kB  quantiphy/examples
1.54 kB  quantiphy/doc
3.48 MB  quantiphy
```

6.3.8 Parameterized Simulation Example

In this example, Python is used to perform a simulation of a $\Delta\Sigma$ modulator. There are a collection of parameters that control the simulation, which are placed at the top of the Python file as documentation. `quantiphy.Quantity.extract()` is used to access these parameters and control the simulation. In this way, modifying the simulation parameters is easy and the documentation is always up to date.

```
#!/usr/bin/env python3

r"""
Simulates a second-order  $\Delta\Sigma$  modulator with the following parameter values:

    Fclk = 50MHz           -- clock frequency
    Fin = 200kHz          -- input frequency
    Vin = 950mV           -- input voltage amplitude (peak)
    gain1 = 0.5           -- gain of first integrator
    gain2 = 0.5           -- gain of second integrator
    Vmax = 1V             -- quantizer maximum input voltage
    Vmin = -1V           -- quantizer minimum input voltage
```

(continues on next page)

(continued from previous page)

```
# levels = 16          -- quantizer output levels
levels = 4            -- quantizer output levels
Tstop = 1/Fin "s"    -- simulation stop time
Tstart = -0.5/Fin "s" -- simulation start time (points with t<0 are discarded)
vin_file = 'vin.wave' -- output data file for vin
vout_file = 'vout.wave' -- output data file for vout
dout_file = 'dout.wave' -- output data file for dout
```

The values given above are used in the simulation, no further modification of the code given below is required when changing these parameters.

```
"""
from quantiPHY import Quantity
from math import sin, tau
from inform import display, error, os_error

class Integrator:
    def __init__(self, gain=1):
        self.state = 0
        self.gain = gain

    def update(self, vin):
        self.state += self.gain*vin
        return self.state

class Quantizer:
    def __init__(self, v_max, v_min, levels):
        self.v_min = v_min
        self.levels = levels
        self.delta = (v_max - v_min)/(levels - 1)

    def update(self, v_in):
        level = (v_in - self.v_min) // self.delta
        level = 0 if level < 0 else level
        level = self.levels-1 if level >= self.levels else level
        return int(level), self.delta*level + self.v_min

class Source:
    def __init__(self, f_in, amp):
        self.omega = tau*f_in
        self.amp = amp

    def update(self, t):
        return self.amp*sin(self.omega*t)

# read simulation parameters and load into module namespace
parameters = Quantity.extract(__doc__)
globals().update(parameters)

# display the simulation parameters
display('Simulation parameters:')
for k, v in parameters.items():
    try:
        display(f'    {k}, v.render(show_label='f')')

```

(continues on next page)

(continued from previous page)

```

except AttributeError:
    display(f'      {k} = {v}')

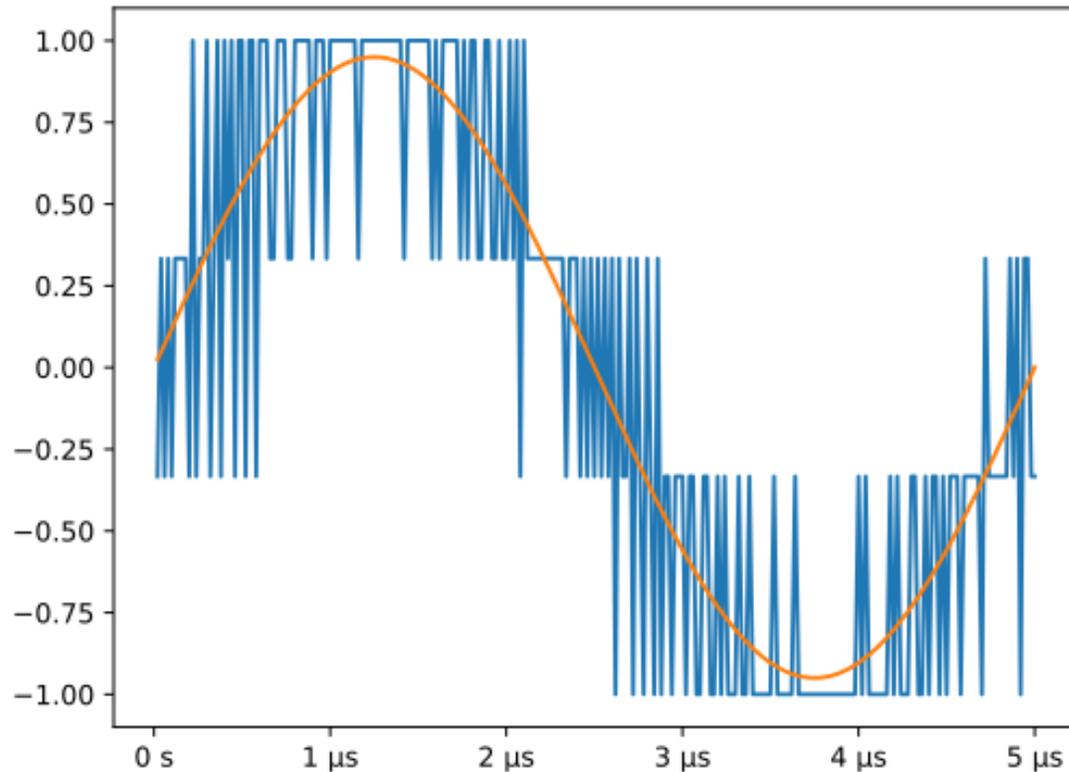
# instantiate components
integrator1 = Integrator(gain1)
integrator2 = Integrator(gain2)
quantizer = Quantizer(Vmax, Vmin, levels)
sine = Source(Fin, Vin)

# run simulation
t = Tstart
dt = 1/Fclk
v_out = 0
t_stop = Tstop
try:
    fvin = open(vin_file, 'w')
    fvout = open(vout_file, 'w')
    fdout = open(dout_file, 'w')
    while t < t_stop:
        v_in = sine.update(t)
        v_int1 = integrator1.update(v_in - v_out)
        v_int2 = integrator2.update(v_int1 - v_out)
        d_out, v_out = quantizer.update(v_int2)
        if (t >= 0):
            print(t, v_in, file=fvin)
            print(t, v_out, file=fvout)
            print(t, d_out, file=fdout)
        t += dt
except OSError as e:
    error(os_error(e))

```

Notice that *levels* was specified twice, but the first proceeded by *#* causing it to be ignored.

The output of this example can be used as the input to the next. With these parameters, it produces this waveform:



6.3.9 Matplotlib Example

In this example *QuantiPhy* is used to create easy to read axis labels in Matplotlib. It uses NumPy to do a spectral analysis of a signal and then produces an SVG version of the results using Matplotlib.

```
#!/usr/bin/env python3

import numpy as np
from numpy.fft import fft, fftfreq, fftshift
import matplotlib as mpl
mpl.use('SVG')
from matplotlib.ticker import FuncFormatter
import matplotlib.pyplot as plt
from quantiphy import Quantity
Quantity.set_prefs(map_sf=Quantity.map_sf_to_sci_notation)

# read the data from delta-sigma.smpl
data = np.fromfile('delta-sigma.smpl', sep=' ')
time, wave = data.reshape((2, len(data)//2), order='F')

# print out basic information about the data
timestep = Quantity(time[1] - time[0], name='Time step', units='s')
nonperiodicity = Quantity(wave[-1] - wave[0], name='Nonperiodicity', units='V')
points = Quantity(len(time), name='Time points')
```

(continues on next page)

(continued from previous page)

```

period = Quantity(timestep * len(time), name='Period', units='s')
freq_res = Quantity(1/period, name='Frequency resolution', units='Hz')
with Quantity.prefs(show_label=True, prec=2):
    print(timestep, nonperiodicity, points, period, freq_res, sep='\n')

# create the window
window = np.kaiser(len(time), 11)/0.37
    # beta=11 corresponds to alpha=3.5 (beta = pi*alpha)
    # the processing gain with alpha=3.5 is 0.37
windowed = window*wave

# transform the data into the frequency domain
spectrum = 2*fftshift(fft(windowed))/len(time)
freq = fftshift(fftfreq(len(wave), timestep))

# define the axis formatting routines
freq_formatter = FuncFormatter(lambda v, p: str(Quantity(v, 'Hz')))
volt_formatter = FuncFormatter(lambda v, p: str(Quantity(v, 'V')))

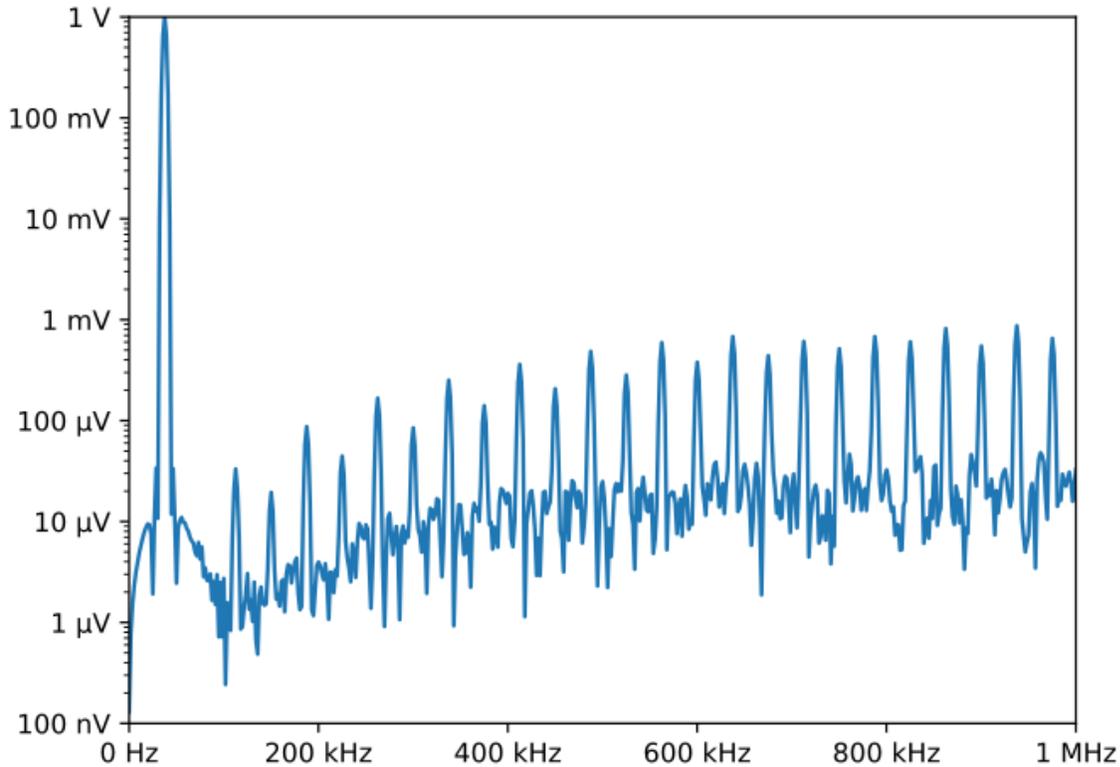
# generate graphs of the resulting spectrum
fig = pl.figure()
ax = fig.add_subplot(111)
ax.plot(freq, np.absolute(spectrum))
ax.set_yscale('log')
ax.xaxis.set_major_formatter(freq_formatter)
ax.yaxis.set_major_formatter(volt_formatter)
pl.savefig('spectrum.svg')
ax.set_xlim((0, 1e6))
ax.set_ylim((1e-7, 1))
pl.savefig('spectrum-zoomed.svg')
    
```

This script produces the following textual output:

```

Time step = 20 ns
Nonperiodicity = 2.3 pV
Time points = 28k
Period = 560 μs
Frequency resolution = 1.79 kHz
    
```

And the following is one of the two graphs produced:



Notice the axis labels in the generated graph. Use of *QuantiPhy* makes the widely scaled units compact and easy to read.

Matplotlib provides the [EngFormatter](#) that you can use as an alternative to *QuantiPhy* for formatting your axes with SI scale factors, which also provides the `format_eng` function for converting floats to strings formatted with SI scale factors and units. So if your needs are limited, as they are in this example, that is generally a good way to go. One aspect of *QuantiPhy* that you might prefer is the way it handles very large or very small numbers. As the numbers get either very large or very small *EngFormatter* starts by using unfamiliar scale factors (*YZPEzy*) and then reverts to e-notation. *QuantiPhy* allows you to control whether to use unfamiliar scale factors but does not use them by default. It also can be configured to revert to engineering scientific notation (ex: 13.806×10^{24} J/K) when no scale factors are appropriate. Though not necessary for this example, that was done above with the line:

```
Quantity.set_prefs(map_sf=Quantity.map_sf_to_sci_notation)
```

6.3.10 Cryptocurrency Example

This example displays the current price of various cryptocurrencies and the total value of a hypothetical portfolio of currencies. *QuantiPhy* performs conversions from the prices of various currencies to dollars. The latest prices are downloaded from [cryptocompare.com](#). A summary of the prices is printed and then they are multiplied by the portfolio holdings to find the total worth of the portfolio, which is also printed.

It demonstrates some of the features of *UnitConversion*.

```
#!/usr/bin/env python3

import requests
from inform import display, fatal, os_error, terminate
from quantiphy import Quantity, UnitConversion, InvalidNumber
Quantity.set_prefs(prec=2)

# read holdings
try:
    with open('holdings') as f:
        lines = f.read().splitlines()
        holdings = {
            q.units: q for q in [
                Quantity(l, ignore_sf=True) for l in lines if l
            ]
        }
except OSError as e:
    fatal(os_error(e))
except InvalidNumber as e:
    fatal(e)

# download latest asset prices from cryptocompare.com
currencies = dict(
    fsyms = ','.join(holdings.keys()), # from symbols
    tsyms = 'USD', # to symbols
)
url_args = '&'.join(f'{k}={v}' for k, v in currencies.items())
base_url = f'https://min-api.cryptocompare.com/data/pricemulti'
url = '?'.join([base_url, url_args])
try:
    response = requests.get(url)
except KeyboardInterrupt:
    terminate('Killed by user.')
except Exception as e:
    fatal('cannot connect to cryptocompare.com.')
conversions = response.json()

# define unit conversions
converters = {
    sym: UnitConversion(('$', 'USD'), sym, conversions[sym]['USD'])
    for sym in holdings
}

# sum total holdings
total = Quantity(sum(q.scale('$') for q in holdings.values()), '$')

# show summary of holdings and conversions
for sym, q in holdings.items():
    value = f'{q:>9q} = {q:<7q$} {100*q.scale("$")/total:.0f}%'
    price = f'1 {sym} = {converters[sym].convert()}'
    display(f'{value:<25s} ({price})')
display(f'    Total = {total:q}')
```

This script reads a file ‘holdings’ that contains the number of tokens you hold of each of your cryptocurrencies. That file would contain one currency per line and look like this:

```
10 BTC
```

(continues on next page)

(continued from previous page)

```
100 ETH
100 BCH
100 ZEC
10,000 EOS
100,000 ADA
```

The output of the script looks like this:

```
 10 BTC = $65.8k  30%  (1 BTC = $6.58k)
100 ETH = $22.4k  10%  (1 ETH = $224)
100 BCH = $51.5k  24%  (1 BCH = $515)
100 ZEC = $12.7k  6%   (1 ZEC = $127)
 10 kEOS = $57.6k  26%  (1 EOS = $5.76)
100 kADA = $8.16k  4%   (1 ADA = $81.6m)
  Total = $218k
```

If you prefer the output in fixed-point format, you can replace the last part of this code with:

```
# show summary of holdings and conversions
for sym, q in holdings.items():
    value = f'{q:>10.2p} = {q:>#11,.2p$}  {100*q.scale("$")/total:,.0f}%'
    price = f'1 {sym} = {converters[sym].convert():>#9,.2p}'
    display(f'{value:<30s} ({price})')
display(f'      Total = {total:>#11,.2p}')
```

If you do, the output of the script looks like this:

```
 10 BTC = $65,847.10  30%  (1 BTC = $6,584.71)
100 ETH = $22,401.00  10%  (1 ETH = $224.01)
100 BCH = $51,450.00  24%  (1 BCH = $514.50)
100 ZEC = $12,726.00  6%   (1 ZEC = $127.26)
10000 EOS = $57,600.00  26%  (1 EOS = $5.76)
100000 ADA = $8,203.00  4%   (1 ADA = $0.08)
  Total = $218,227.10
```

A more sophisticated version of this example can be found on [Github](#).

6.3.11 RKM Codes Example

RKM codes are a way of writing numbers that is often used for specifying the sizes of resistors and capacitors on schematics and on the components themselves. In RKM codes the radix is replaced by the scale factor and the units are suppressed. Doing so results in a compact representation that is less likely to be misinterpreted if the number is poorly rendered. For example, a $6.8\text{K}\Omega$ could be read as $68\text{K}\Omega$ if the decimal point is somehow lost. The RKM version of $6.8\text{K}\Omega$ is $6\text{K}8$. RKM codes are described on [Wikipedia](#).

QuantiPhy does not support RKM codes directly, but you can download a companion package `rkm_codes` from GitHub, or you can download and install it with pip:

```
pip3 install --user rkm_codes
```

Originally RKM codes were limited to resistors and capacitors. IEC60062 is an international standard that codifies RKM codes for this use. It assumes that large values are resistances and small values are capacitances, thus it is not really necessary to include the units with the number. The `rkm_codes` package provides a more general version of RKM codes which includes the units by default, but it can be configured to conform to the standard by setting `rkm_maps` as follows:

```

>> from rkm_codes import from_rkm, to_rkm
>> from rkm_codes import set_prefs, IEC60062_MAPS
>> set_prefs(rkm_maps=IEC60062_MAPS)

>> r = from_rkm('6k8')
>> r
Quantity('6.8 kΩ')

>> c = from_rkm('4u7')
>> c
Quantity('4.7 μF')

>> to_rkm(r)
'6k8'

>> to_rkm(c)
'4u7'
    
```

You can also use RKM codes for values other than just resistances and capacitances. In this case, the RKM codes are treated as being unitless, but you can specify the units along with the RKM code.

```

>> from rkm_codes import from_rkm, to_rkm
>> from rkm_codes import set_prefs, UNITLESS_MAPS
>> set_prefs(rkm_maps=UNITLESS_MAPS)

>> r = from_rkm('6k8')
>> r
Quantity('6.8k')

>> r = from_rkm('6k8Ω')
>> r
Quantity('6.8 kΩ')

>> i = from_rkm('2n5A')
>> i
Quantity('2.5 nA')

>> to_rkm(i)
'2n5'

>> to_rkm(i, show_units=True)
'2u5A'
    
```

This is the default mode of *rkm_codes*, so it is not necessary to use *set_prefs* to explicitly set *rkm_maps* to *UNITLESS_MAPS* if you prefer this mode.

As a practical example of the use of RKM codes, imagine wanting a program that creates pin names for an electrical circuit based on a naming convention. It would take a table of pin characteristics that are used to create the names.

For example:

```

>> from quantiphy import Quantity
>> from rkm_codes import to_rkm, set_prefs as set_rkm_prefs

>> pins = [
..     dict(kind='ibias', direction='out', polarity='sink', dest='dac', value='250nA
↪'),
..     dict(kind='ibias', direction='out', polarity='src', dest='rampgen', value='2.
↪5μA'),
    
```

(continues on next page)

(continued from previous page)

```

..     dict(kind='vref', direction='out', dest='dac', value='1.25V'),
..     dict(kind='vdda', direction='in', value='2.5V'),
.. ]
>> set_rkm_prefs(map_sf={}, units_to_rkm_base_code=None)

>> for pin in pins:
..     components = []
..     if 'value' in pin:
..         pin['VALUE'] = to_rkm(Quantity(pin['value']))
..     for name in ['dest', 'kind', 'direction', 'VALUE', 'polarity']:
..         if name in pin:
..             components.append(pin[name])
..     print('.'.join(components))
dac_ibias_out_250n_sink
rampgen_ibias_out_2u5_src
dac_vref_out_1v2
vdda_in_2v5

```

6.4 Releases

1.0 (2016-11-26):

- initial production release.

1.1 (2016-11-27):

- added *known_units* preference.
- added *get_preference* class method.

1.2 (2017-02-24):

- allow digits after decimal point to be optional
- support underscores in numbers
- allow options to be monkey-patched on to Quantity objects
- add *strip_dp* option
- fix some issues in full precision mode
- renamed some options, arguments and methods

1.3 (2017-03-19):

- reworked constants
- added unit systems for physical constants

2.0 (2017-07-15): This is a ‘coming of age’ release where the emphasis shifts from finding the right interface to providing an interface that is stable over time. This release includes the first formal documentation and a number of new features and refinements to the API.

- created formal documentation
- enhanced *label_fmt* to accept {V}
- allow quantity to be passed as value to *quantiphy.Quantity*
- replaced *Quantity.add_to_namespace* with *quantiphy.Quantity.extract()*

- raise *NameError* rather than *AssertionError* for unknown preferences
- added `quantiphy.Quantity.all_from_conv_fmt()` and `quantiphy.Quantity.all_from_si_fmt()`
- change *assign_rec* to support more formats
- changed *Constant()* to `quantiphy.add_constant()`
- changed the way preferences are implemented
- changed name of preference methods: *set_preferences* → *set_prefs*, *get_preference* → *get_pref*
- added `quantiphy.Quantity.prefs()` (preferences context manager)
- split *label_fmt* preference into two: *label_fmt* and *label_fmt_full*
- added *show_desc* preference
- allow *show_label* to be either 'a' or 'f' as well True or False
- renamed *strip_dp* option to *strip_radix*
- added *number_fmt* option

2.1 (2017-07-30): The primary focus of this release was on improving the documentation, though there are a few small feature enhancements.

- added support for SI standard composite units
- added support for non-breaking space as spacer
- removed constraint in `quantiphy.Quantity.extract()` that names must be identifiers

2.2 (2017-11-22):

- added `quantiphy.Quantity.scale()`
- added `quantiphy.UnitConversion.convert()`
- added *strip_zeros*
- added no-op conversions (units change but value stays the same, ex: \$ → USD)

2.3 (2018-03-11):

- enhanced `quantiphy.Quantity.extract()`
 - non-conforming lines are now ignored
 - values may be expressions
 - values need not be quantities
 - can specify a quantity name distinct from dictionary name
- enhanced the formatting capabilities.
 - added center alignment
 - added *p* format
 - added *show_commas* preference.
 - added *strip_zeros*, *strip_radix* to `quantiphy.Quantity.render()`
 - added `quantiphy.Quantity.fixed()` method
 - added `quantiphy.Quantity.format()` method
 - support any format specifier supported by Python for floats

2.4 (2018-09-12):

- fixed bug in format that resulted in several format codes ignoring width
- follow Python convention of right-justifying numbers by default.
- add `Quantity.add()` (adds a number to a quantity returning a new quantity)
- added `#` alternate form of string formatting.
- Change `show_si` to `form` (argument on `quantiphy.Quantity.set_prefs()` and `quantiphy.Quantity.render()` (`show_si` is now obsolete, use `form='si'` instead).
- Added concept of equivalent units for unit conversion to documentation.
- Enhance `UnitConversion` so that it supports nonlinear conversions.

2.5 (2019-01-16):

- added RKM codes example.
- added `check_value = 'strict'` to `quantiphy.Quantity.add()`.
- added backward compatibility for `form` argument of `quantiphy.Quantity.render()` if it is passed as unnamed argument.
- made `quantiphy.Quantity.extract()` a bit more general.
- reformulated exceptions.
- added support for binary scale factors and `quantiphy.Quantity.binary()`.

Latest development release:

Version: 2.5.0

Released: 2019-01-16

A

add() (quantiphy.Quantity method), 43
add_constant() (in module quantiphy), 60
all_from_conv_fmt() (quantiphy.Quantity class method), 44
all_from_si_fmt() (quantiphy.Quantity class method), 44
as_tuple() (quantiphy.Quantity method), 44

B

binary() (quantiphy.Quantity method), 45

C

convert() (quantiphy.UnitConversion method), 59

D

dB, 19, 25, 32

E

ExpectedQuantity (class in quantiphy), 61
extract() (quantiphy.Quantity class method), 46

F

fixed() (quantiphy.Quantity method), 47
format() (quantiphy.Quantity method), 48

G

get_pref() (quantiphy.Quantity class method), 49

I

IncompatibleUnits (class in quantiphy), 61
InvalidNumber (class in quantiphy), 61
InvalidRecognizer (class in quantiphy), 61
is_close() (quantiphy.Quantity method), 50
is_infinite() (quantiphy.Quantity method), 50
is_nan() (quantiphy.Quantity method), 50

K

Kelvin/kilo ambiguity, 34

L

logarithmic units, 32

M

map_sf_to_greek() (quantiphy.Quantity static method), 50
map_sf_to_sci_notation() (quantiphy.Quantity static method), 51
meter/milli ambiguity, 33
MissingName (class in quantiphy), 61

P

prefs() (quantiphy.Quantity class method), 51

Q

QuantiPhyError (class in quantiphy), 61
Quantity (class in quantiphy), 42

R

render() (quantiphy.Quantity method), 51

S

scale() (quantiphy.Quantity method), 53
set_prefs() (quantiphy.Quantity class method), 53
set_unit_system() (in module quantiphy), 60

U

UnitConversion (class in quantiphy), 57
UnknownConversion (class in quantiphy), 61
UnknownFormatKey (class in quantiphy), 61
UnknownPreference (class in quantiphy), 61
UnknownScaleFactor (class in quantiphy), 61
UnknownUnitSystem (class in quantiphy), 61