

# Measurement

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## Base and Derived Units

- Science depends on measuring physical quantities (e.g. length, time, mass, temperature)
- A **unit** is a measure of a physical quantity.  
ex: the unit *meter* is a certain quantity of *length*
- Some physical quantities (called base quantities) have their own units associated with them (called base units)  
ex: the base unit of *length* is the *meter* (m) and the base unit of *time* is the *second* (s).
- Some physical quantities (called derived quantities) are expressed as combinations of these base units  
ex: the derived unit for speed is meter/second (m/s).

# Systems of Units

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## Systeme International (SI)

- Defining a complete set of base units defines a system
- Most physical sciences use the SI set of units
- Base SI units include the *meter* (quantity of *length*), the *second* (quantity of *time*), and the *kilogram* (quantity of *mass*).
- **SI prefixes:** kilo- ( $10^3$ ), centi- ( $10^{-2}$ ), milli- ( $10^{-3}$ ), micro ( $10^{-6}$ ). See table 1-4 for additional prefixes.
- We use prefixes to modify the physical quantity measured by these units.
  - ex: one *kilometer* is 1 000 times more length than one *meter*.
  - ex: one *microsecond* is 1 000 000 times less time than one *second*.

# Base and Derived Units

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## SI Base Units

**Time:** The SI unit of time is the *second* (s), which is defined as the time taken by 9 192 631 770 oscillations of the light emitted by a cesium-133 atom.

**Mass:** The SI unit of mass is the *kilogram* (kg) is defined by a platinum-iridium standard kept near Paris.

**Length:** The SI unit of length is the *meter* (m) defined as 1/299 792 458 times the distance that light travels in a vacuum in one second.

## Derived Units

• These SI *base units* are combined to form *derived units*, used for measuring physical quantities beyond length, time, and mass.

ex: *speed* is a distance (quantity length) over a time, so the derived unit for speed is  $m \text{ (length)}/s \text{ (time)}$ .

ex: *force* is an acceleration times a mass, which leads to derived units of  $kg \text{ m}/s^2$

# Dimensional analysis

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- The *dimension* of a quantity  $q$ , denoted  $[q]$ , reflects the measurable properties of  $q$  **independent of units**.
- These measurable properties include length (L), time (T), and mass (M).  
ex.  $[\rho]=ML^{-3}$
- For two physical quantities  $x$  and  $y$  to be equal it is *necessary* that they have the same dimensionality or  $[x]=[y]$ .
- Therefore, to determine whether two quantities are equal one needs first to determine whether they have the same units. If they have different units, they *cannot* be equal.  
ex. If  $X$  and  $Y$  are numbers  $X \text{ kg m/s}^3$  cannot equal  $Y \text{ m/s}^2$  because the units are different

# Unit Conversion

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- We can change between different units measuring the same physical quantity.
- We *cannot* change between different units measuring different physical quantities (see discussion on dimensional analysis).
- A **conversion factor** is a multiplicative factor relating the two units. Numerically, this conversion factor must equal **1**.
  - ex A:  $1 \text{ min} = 60 \text{ s}$  so the conversion factor is  $1 \text{ min}/60 \text{ s}$  ( $=1$ ).
  - ex B:  $1 \text{ min} = 60 \text{ s}$  so the conversion factor is  $60 \text{ s}/1 \text{ min}$  ( $=1$ ).
- We choose a conversion factor based on the units given in the problem.
  - ex. To express 16 minutes in units of seconds, the conversion factor from example B above would be the appropriate choice.
- We can find conversion factors between units measuring the same physical quantity in different systems.
  - ex.  $1 \text{ mile} = 1\,609 \text{ m}$  so the conversion factor is  $1 \text{ mile}/1\,609 \text{ m}$  ( $=1$ ).

# Working with units

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**Always** include units in your final answer. The car was not traveling at 10, the car was traveling at 10 m/s

**Always** include units during each intermediate step. This will help you determine whether or not you need to include a conversion factor to change the units

**Always** check that your answer has units appropriate for expressing the physical quantity (dimensional analysis). The car was also not traveling at 10 kg m/s<sup>2</sup>.

## Order of magnitude estimates

- In order to obtain an approximate (or “order-of-magnitude”) estimate for some quantity, it is often useful to estimate other quantities (which can be guessed more accurately) and combine these quantities into your final estimate.
  - ex. If asked how many tennis racquets there are in the US, estimate the US population (say  $3 \times 10^8$ ), then guess that 20% of people play tennis, giving a total of 60 million racquets.

# Significant figures

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**Significant figures.** Measuring physical quantities always has some uncertainty. The number of significant figures (the number of digits given) reflects this uncertainty.

ex. 5 s has one significant figure. 5.2 s has two significant figures, as does 5.0 s. 0.5 s has one significant figure, as does 0.0005 s.

Your final answer should include the same number of significant figures as the quantity with the least number of significant figures in the given data.

ex. A rectangle with sides of 1.13789 m and 2 m has an area of 2 m<sup>2</sup>.