Measurement

**Learning objectives**

* Use the [SI](javascript:definition('sI');) system.
  + Know the SI [base units](javascript:definition('base+unit');).
  + State [rough equivalents for the SI base units](http://antoine.frostburg.edu/chem/senese/101/measurement/SIbaseunits.shtml) in the English system.
  + Read and write the [symbols](http://antoine.frostburg.edu/chem/senese/101/measurement/SIbaseunits.shtml) for SI units.
  + Recognize [unit prefixes](http://antoine.frostburg.edu/chem/senese/101/measurement/SIprefixes.shtml) and their abbreviations.
  + Build [derived units](javascript:definition('derived+unit');) from the basic units for mass, length, temperature, and time.
  + Use derived units like [density](javascript:definition('density');) and speed as conversion factors.
* Use and report measurements carefully.
  + Consider the reliability of a measurement in decisions based on measurements.
  + Clearly distinguish between
    - [precision](javascript:definition('precision');) and [accuracy](javascript:definition('accuracy');)
    - exact numbers and [measurements](javascript:definition('measurement');)
  + Count the number of [significant figures](javascript:definition('significant+figure');) in a recorded measurement. Record measurements to the correct number of digits.
  + Estimate the number of significant digits in a calculated result.

**Outline**

Measurement is the collection of quantitative data. The proper handling and interpretation of measurements are essential in chemistry - and in any scientific endeavour. To use measurements correctly, you must recognize that measurements are not numbers. They always contain a unit and some inherent error. The second lecture focuses on an international system of units (the SI system) and introduces unit conversion. In the third lecture, we'll discuss ways to recognize, estimate and report the errors that are always present in measurements.

**Measurement**

* quantitative observations
* include 3 pieces of information
  + magnitude
  + unit
  + uncertainty
* measurements are not numbers
  + numbers are obtained by counting or by definition; measurements are obtained by comparing an object with a standard "unit"
  + numbers are exact; measurements are inexact
  + mathematics is based on numbers; science is based on measurement

**The SI System**

* *Le Systéme Internationale* (SI) is a set of units and notations that are standard in science.

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| Four important SI base units (there are [others](http://antoine.frostburg.edu/chem/senese/101/measurement/SIbaseunits.shtml)) | | |
| **Quantity** | **SI Base Unit** | **English Equivalent** |
| length | meter (m) | 1 m = 39.36 in |
| mass | kilogram (kg) | 1 kg = 2.2 lbs |
| time | second (s) |  |
| temperature | kelvin (K) | °F = 1.8(oC)+32 K = °C + 273.15 |
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* derived units are built from base units

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| Some SI derived units | | | |
| Quantity | Dimensions | SI units | Common name |
| area | length × length | m2 | square meter |
| velocity | length/time | m/s |  |
| density | mass/volume | kg/m3 |  |
| frequency | cycles/time | s-1 | hertz (Hz) |
| acceleration | velocity/time | m/s2 |  |
| force | mass × acceleration | kg m/s2 | Newton (N) |
| work, energy, heat | force × distance | kg m2/s2 | Joule (J) |
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* Prefixes are used to adjust the size of base units

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| Commonly used SI prefixes (there are [others](http://antoine.frostburg.edu/chem/senese/101/measurement/SIprefixes.shtml)). | | | |
| **Prefix** | **Meaning** | **Abbreviation** | **Exponential Notation** |
| Giga- | billion | G | 109 |
| Mega- | million | M | 106 |
| kilo- | thousand | k | 103 |
| centi- | hundredths of | c | 10-2 |
| milli- | thousandths of | m | 10-3 |
| micro- | millionths of | µ | 10-6 |
| nano- | billionths of | n | 10-9 |
| pico- | trillionths of | p | 10-12 |
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* several non-SI units are encountered in chemistry

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| **Non SI unit** | **Unit type** | **SI conversion** | **Notes** |
| liter (L) | volume | 1 L = 1000 cm3 | 1 quart = 0.946 L |
| Angstrom (Å) | length | 1 Å = 10-10 m | typical radius of an atom |
| atomic mass unit (u) | mass | 1 u = 1.66054×10-27 kg | about the mass of a proton or neutron; also known as a 'dalton' or 'amu' |

**Arithmetic with units**

* addition and subtraction: units don't change  
  2 kg + 3 kg = 5 kg  
  412 m - 12 m = 400 m
  + consequence: units must be the same before adding or subtracting!  
    3.001 kg + 112 g = 3.001 kg + 0.112 kg = 3.113 kg  
    4.314 Gm - 2 Mm = 4.314 Gm - 0.002 Gm = 4.312 Gm
* multiplication and division: units multiply & divide too  
  3 m × 3 m = 9 m2  
  10 kg × 9.8 m/s2 = 98 kg m/s2
  + consequence: units may cancel  
    5 g / 10 g = 0.5 (no units!)  
    10.00 m/s × 39.37 in/m = 393.7 in/s

**Converting Units**

* 5 step plan for converting units
  1. identify the unknown, including units
  2. choose a starting point
  3. list the connecting conversion factors
  4. multiply starting measurement by conversion factors
  5. check the result: does the answer make sense?
* Common variations
  1. series of conversions
     + example: *Americium (Am) is extremely toxic; 0.02 micrograms is the allowable body burden in bone. How many ounces of Am is this?*
  2. converting powers of units
  3. converting compound units
  4. starting point must be constructed
* using derived units as conversion factors
  1. mass fractions (percent, ppt, ppm) convert mass of sample into mass of component
  2. density converts mass of a substance to volume
  3. velocity converts distance traveled to time required
  4. concentration converts volume of solution to mass of solute

**Uncertainty in Measurements**

* significant digits
  + definition: all digits up to and including the first uncertain digit.
  + the more significant digits, the more reproducible the measurement is.
  + *counts and defined numbers are exact- they have no uncertain digits!*
* counting significant digits in a single measurement
  + convert to exponential notation
  + disappearing zeros just hold the decimal point- they aren't significant.
  + exception: zeros at the end of a whole number *might* be significant
* Precision of Calculated Results
  + calculated results are never more reliable than the measurements they are built from
  + multistep calculations: never round intermediate results!
  + sums and differences: round result to the same number of *fraction digits* as the poorest measurement
  + products and quotients: round result to the same number of *significant digits* as the poorest measurement.
* Precision vs. Accuracy

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| good precision & good accuracy  poor accuracy but good precision | Accuracy vs. Precision | good accuracy but poor precision  poor precision & poor accuracy |



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| **Precision** | **Accuracy** |
| reproducibility | correctness |
| check by repeating measurements | check by using a different method |
| poor precision results from poor technique | poor accuracy results from procedural or equipment flaws |
| poor precision is associated with 'random errors' - error has random sign and varying magnitude. Small errors more likely than large errors. | poor accuracy is associated with 'systematic errors' - error has a reproducible sign and magnitude. |

* Estimating Precision
  + Consider these two methods for computing scores in archery competitions. Which is fairer?

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| 1-2-3 | Score by distance from bullseye |
| 1-4-9 | Score by area or target |