Measurement and Uncertainty

What is a Measurement?

- A measurement tells us about a property of something
  - how heavy an object is
  - how hot
  - how long it is
- A measurement gives a number to that property

- Measurements are always made using an instrument of some kind
  - rulers
  - stopwatches
  - balances
  - thermometers

- The result of a measurement is in two parts: a number and a unit of measurement
  - 2 m
  - 20 °C
  - 15 ms^{-1}

What is Not a Measurement?

- There are some processes that might seem to be measurements, but are not
  - comparing two pieces of string to see which is longer
  - counting

What is uncertainty of measurement?

- The uncertainty of a measurement tells us something about its quality.
- Uncertainty of measurement is the doubt that exists about the result of any measurement

- You might think that well-made rulers, clocks and thermometers should be trustworthy, and give the right answers.
- But for every measurement - even the most careful - there is always a margin of doubt.

Expressing uncertainty of measurement

- Since there is always a margin of doubt about any measurement, we need to ask ‘How big is the margin?’ and ‘How bad is the doubt?’
- Two numbers are needed to quantify an uncertainty
  - the width of the margin, or ***interval***
  - the other is a ***confidence level***

- For example:
  - the length of a certain stick measures 20 cm plus or minus 1 cm, at the 95 percent confidence level
    - 20 cm ±1 cm, at a level of confidence of 95%.
  - The statement says that we are 95 percent sure that the stick is between 19 cm and 21 cm long
  - Note: For our purposes, all of our measurements will be at the 95% confidence level, so we don’t need to specify that

Error versus Uncertainty

- ***Error*** is the difference between the measured value and the ‘true value’ of the thing being measured
- ***Uncertainty*** is a quantification of the doubt about the measurement result

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- Whenever possible we try to correct for any known errors
  - Properly calibrating equipment
  - Redoing measurements that were incorrect
  - Reading the volume on a graduated cylinder at the same angle each time
- Any error whose value we do not know is a source of uncertainty

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Why is uncertainty of measurement important?

- You need to understand the results of a particular experiment
  - Trends may or may not exist depending on how certain your results are
- You may need to meet a certain tolerance
  - Parts manufactures need to make sure that the things they make are the correct size within a small amount of uncertainty

Where do errors and uncertainties come from?

- The measuring instrument
  - bias
  - changes due to ageing and wear
  - poor readability
  - noise (for electrical instruments)

- The item being measured
  - The item may change over time
    - the size of an ice cube in a warm room
- The measurement process
  - the measurement itself may be difficult to make
    - measuring the weight of small but lively animals
- ‘Imported’ uncertainties
  - calibration of your instrument has an uncertainty which is then built into the uncertainty of the measurements you make

- Operator skill
  - one person may be better than another at setting up a measurement
  - reading fine detail by eye
  - the use of a stopwatch depends on the reaction time of the operator
- Sampling issues
  - the measurements you make must be properly representative of the process you are trying to assess
    - If you want to know the temperature at the work-bench, don’t measure it with a thermometer placed on the wall near an air conditioning outlet.

- The environment
  - temperature, air pressure, humidity and many other conditions can affect the measuring instrument or the item being measured

Types of Uncertainty

- ***Random***
  - where repeating the measurement gives a randomly different result
  - the more measurements you make, and then average, the better estimate you generally can expect to get

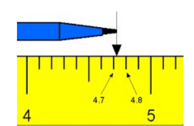
- ***Systematic***
  - where the same influence affects the result for each of the repeated measurements (but you may not be able to tell).
  - you learn nothing extra just by repeating measurements
  - other methods are needed to estimate uncertainties due to systematic effect
    - graphing your results and seeing if the trend line goes through the origin

What is not a measurement uncertainty?

- Mistakes made by operators are not measurement uncertainties
  - They should be avoided by working carefully and by checking work
- Accuracy (or inaccuracy)
  - This is a qualitative term indicating whether the measurement was made properly and carefully

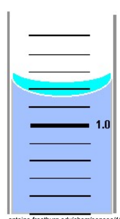
Estimating Uncertainty

- For an analog single measurement we will estimate the uncertainty to be one-half of the smallest indicator on the scale



chemistrymysteries.blogspot.ca/2011/10/measurement-and-uncertainty.html

4.72 ± 0.05 cm



1.16 ± 0.05 ml

antoine.frostburg.edu/chem/senese/101/measurement/slides/sld010.htm

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- For a digital single reading the uncertainty will usually be given by the manufacturer
- If that is not available, then we will estimate it to be the smallest division

www.shopclues.com/fluke-17b-digital-multimeter.html

220.8 ± 0.1 V

www.polder.com/shop/measuring-temperature/food-scales/easy-read-digital-kitchen-scale

112 ± 1 g

- For multiple measurements, the uncertainty of the average (mean) will be estimated to be

$$\frac{\text{maximum value} - \text{minimum value}}{\text{number of measurements}}$$

<u>Data</u>
25.3 cm
24.8 cm
25.2 cm
25.6 cm
25.5 cm

$25.3 \pm 0.2 \text{ cm}$