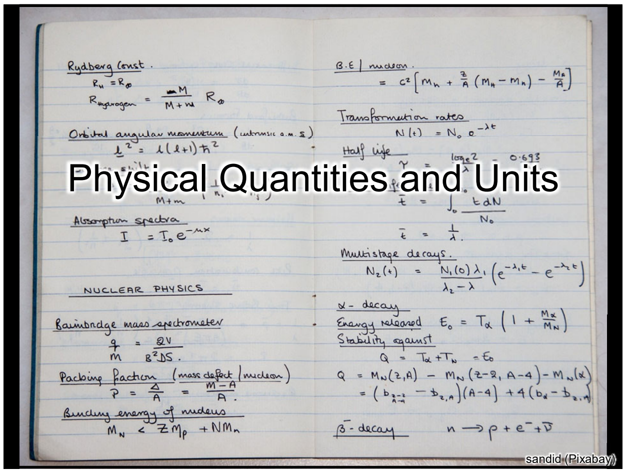



# Physical Quantities and Units

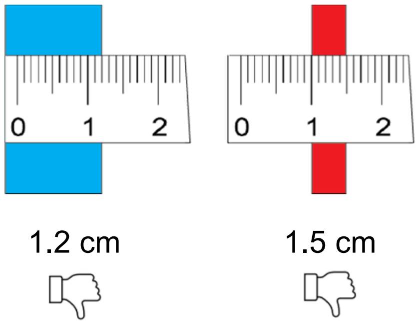
- A physical quantity is defined either by specifying how it is measured or by stating how it is calculated from other measurements.
  - Distance and time are defined by specifying methods for measuring them, whereas we define average speed by stating that it is calculated as distance traveled divided by time of travel.

- Measurements of physical quantities are expressed in terms of standardized values called units.
  - In physics we use fundamental SI units for measurement. (MKS)
    - meter (m)
    - kilogram (kg)
    - second (s)


- Measurement is at the heart of science. In order to do science, we must be able to measure quantities.
- A measurement tells us about the property of something.
  - A number is given to that property.
- When performing measurement there is the possibility of **error** during the measurement and some unavoidable **uncertainty** in the measurement.

## Systematic Errors

- Systematic errors are ones that consistently cause the measurement value to be either too large or too small.
  - This can be caused by faulty or mis-calibrated equipment.
  - These errors can also occur when equipment is used incorrectly.
    - reading from the wrong end of a ruler
    - forgetting to subtract the weight of the container when finding the mass
    - converting units incorrectly




- You may be able to remove a systematic error if you know it exists.
  - Subtracting 5 g from every mass if a balance is mis-calibrated to be 5 g too high.
- In some cases, it can be very difficult to identify systematic errors.
  - The errors often go undiscovered until another measurement is made using a different measuring technique.
- We can never be sure that our experiment is completely free from systematic errors.

- The best way to add confidence to our measurements is to devise an experiment to measure the same quantity by a completely different method that is unlikely to have the same error.
  - If our new technique produces different results, one or both experiments may suffer from unidentified systematic errors.
  - If measurements made with different measurement techniques agree, it suggests that there is no systematic error in either measurement.

## Random Errors

- Random error is when variations in the measurements occur without a predictable pattern.
- If repeated measurements are made, random errors cause the measured value to vary, sometime above and below the actual measured value.
- Because of this, random error causes uncertainty in measurements.

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- We can determine how much random error our measurements have by repeating the measurements many times.
  - If our results are identical or nearly the same, this indicates a small amount of random error.
- Random errors can be reduced, but never eliminated.
  - Taking the average value of multiple measurements reduces the possible effect of random errors.
  - We can then statistically calculate an uncertainty for our measurement.

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## Uncertainties in Measurement

- Uncertainty of measurement is the doubt that exits about the result of any measurement.
  - Two numbers are really needed to quantify an uncertainty.
    - The width of the margin, or interval.
    - The confidence level (how sure we are that the 'true value' is within the indicated margin).

3.25 ± 0.05 m

measurement — margin or interval — units

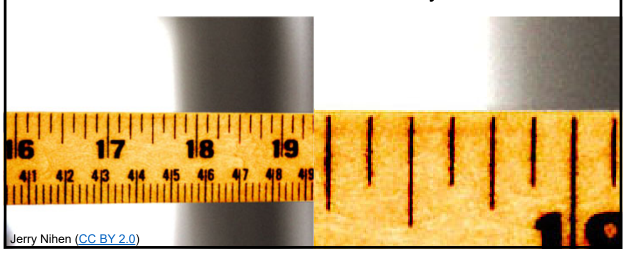
95% confidence is usually assumed unless otherwise stated.

There is a 95% probability that the actual value is between 3.20 and 3.30. In other words, if the experiment was done many times, we would expect 95% of the results to be between 3.20 and 3.30.

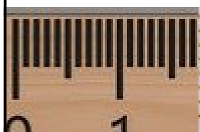
## Determining the Amount of Uncertainty

- Whenever a measurement is made, we can never be certain that the result is exactly correct.
- There is always some difference between the measured value and the actual value, no matter how careful you are or how good your equipment is.

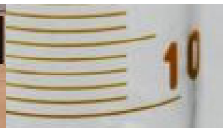
- When measuring something on an analog scale, like a ruler, the measurement will always appear between the marked graduations.
  - The graduations also have width which will also contribute to our uncertainty.



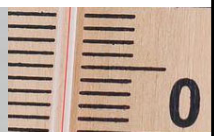
- There is no one set rule that tells exactly how much uncertainty we'll get from an analog scale.
  - A simple starting point is to estimate the uncertainty as one-half of the smallest increment.



±0.0005 m



±0.5 mL



±0.5 °C

Ruler: (Pixabay)
Graduated Cylinder: Linda Pospisilova (CC BY-NC 2.0)
Thermometer: Sookyung An (Pixabay)

- Digital measuring devices are limited to a certain number of digits on the display.
  - The device must round the measurement to the nearest decimal to display it.
  - There are also limitations to the calculations and conversions made within the device that are mostly unknown to the user.

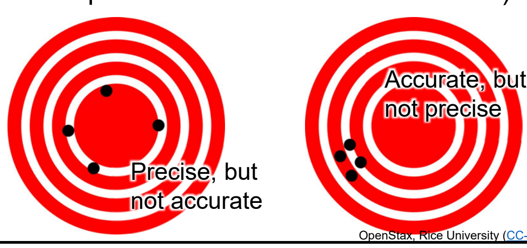
Dmitry (Adobe Stock)

- The manufacturer usually provides an absolute uncertainty or a relative uncertainty as a percent.
- If no uncertain is given, the uncertainty can be estimated to be one-half of the last place value displayed.
  - 1.55 would have an uncertainty of 0.005
  - 1.5 would have an uncertainty of 0.05

## Error vs Uncertainty

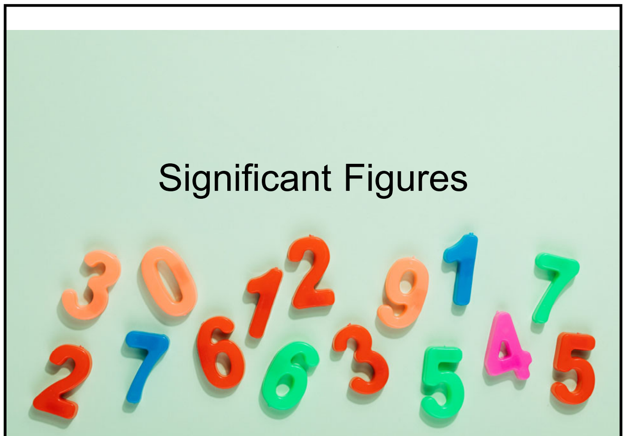
- Error is the difference between the measured value and the true value.
- Uncertainty is a quantification of the doubt about the measurement result.
- Whenever possible we try to correct for any known errors (calibrating equipment). But any error whose value is unknown is a source of uncertainty.


- **Accuracy** is how close a measurement is to the correct value for that measurement.
- The **precision** of a measurement system refers to how close the agreement is between repeated measurements (which are repeated under the same conditions).



- An important factor in the accuracy and precision of measurements involves the precision of the measuring tool.
  - In general, a precise measuring tool is one that can measure values in very small increments.
- The more precise the measuring tool, the more precise and accurate the measurements can be.

krasyuk (Adobe Stock)




Karolina Grabowska (Pexels)

- When we express measured values, we can only list as many digits as we initially measured with our measuring tool.
  - If you use a standard ruler to measure the length of a stick, you may measure it to be 36.7 cm. You could not express this value as 36.71 cm because your measuring tool was not precise enough to measure a hundredth of a centimeter.
- Significant figures are the number of digits in a number that convey meaning.

# Rules

- The last digit written down in a measurement is the first digit with some uncertainty.
- To determine the number of significant digits in a value, start with the first measured value at the left and count the number of digits through the last digit written on the right.

# Zeroes

- Zeros are significant except when they serve only as placekeepers.
  - The zeroes in 0.0045 are not significant as they are placekeepers that locate the decimal place.
  - The zeros in 10.01 are significant since they are not placeholders.

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- The zeroes in 1200 may or may not be significant depending on the style of number.
  - It may have 2, 3, or 4 significant figures.
  - To avoid confusion, we write numbers like this in scientific notation.
    - $1.2 \times 10^3$ has 2 significant figures
    - $1.20 \times 10^3$ has 3 significant figures
    - $1.200 \times 10^3$ has 4 significant figures

## Significant Figures in Calculations

- When combining measurements with different degrees of accuracy and precision, the number of significant digits in the final answer can be no greater than the number of significant digits in the least precise measured value.

- For **multiplication and division**:
  - The result should have the same number of significant figures as the quantity having the least significant figures entering into the calculation.
    - $1.1 \times 2.01 = 2.211 = 2.2$
- For **addition and subtraction**:
  - The answer can contain no more decimal places than the least precise measurement.
    - $8.05 - 2.251 = 5.799 = 5.80$