Uncertainties and errors in measurements and results

Scientific research

When a measurement is recorded, there is always an experimental error or random uncertainty associated with the value.

Uncertainty is the quantification of the doubt in measurement results.

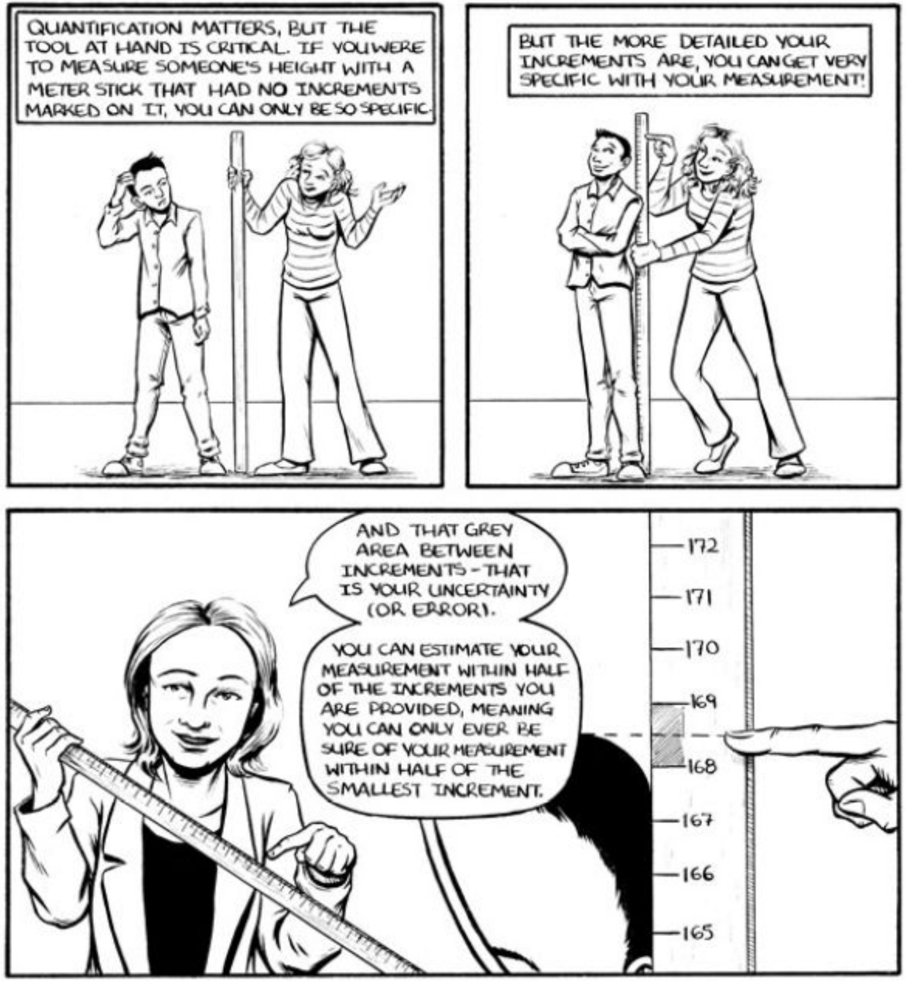
Error can be random or systematic.

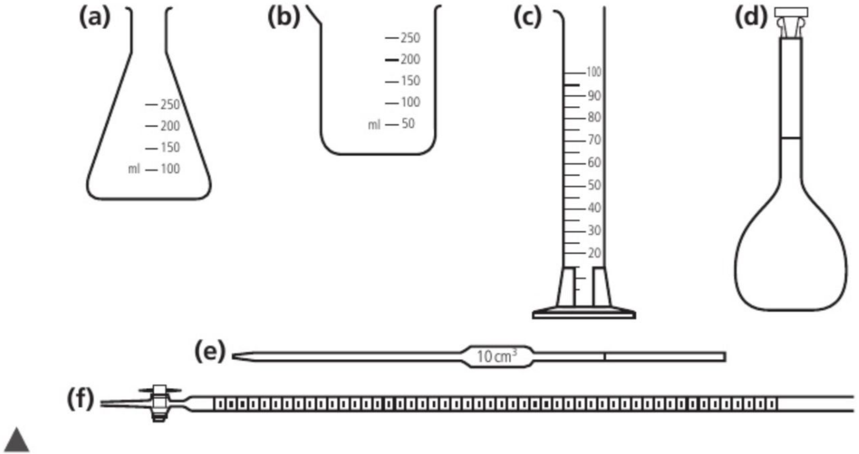
[GCSE Working Scientifically "Uncertainty"]

Estimating the uncertainty

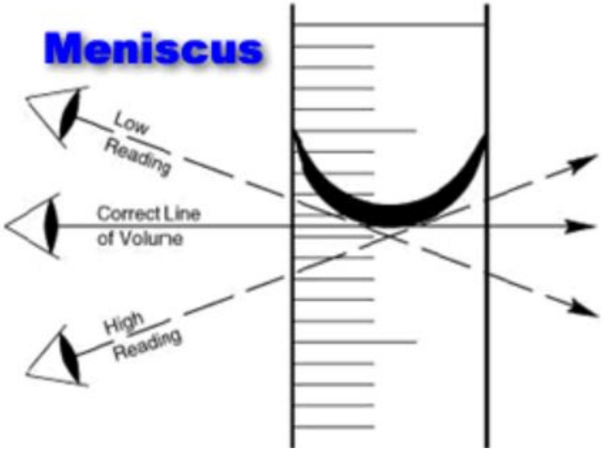
- ➔ ± half of the smallest division on the scale
- ➔ ±1 the last significant figure in a digital measurement
- ➔ Check data provided by the manufacturer

Remember to use SI units!





S1.4 Figure 2 Glassware commonly used in the laboratory. (a) conical or Erlenmeyer flask, its shape makes it easy to mix liquids as the flask can be easily swirled; (b) beaker; (c) measuring or graduated cylinder; (d) volumetric flask; (e) pipette; (f) burette.



Glassware	Volume / cm^3	$\pm$ Uncertainty / cm^3	Uncertainty / %
beaker	50	5	10
measuring cylinder	50.0	0.5	1
burette	50.00	0.05	0.1

Example 1.

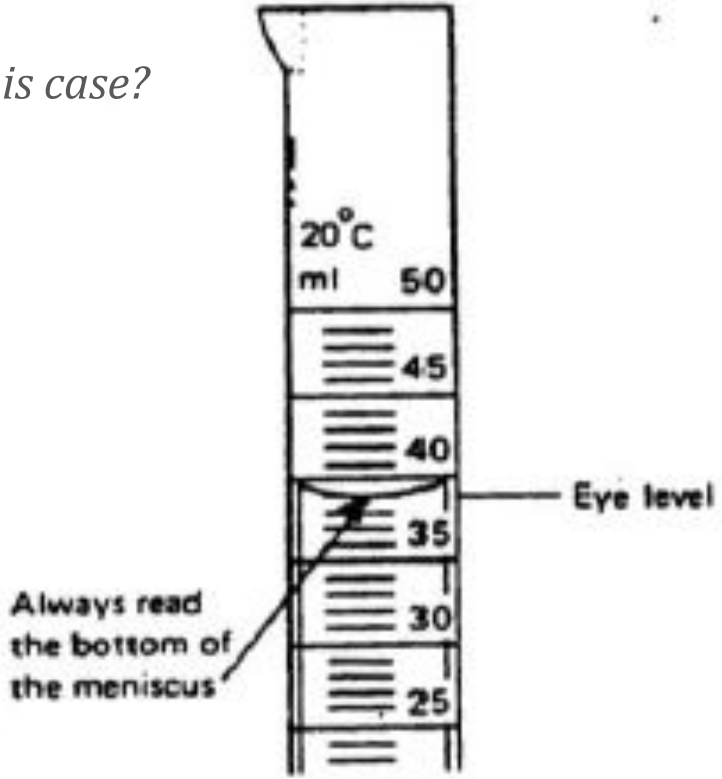
What's the value and measurement uncertainty in this case?

24.20 ± 0.05 ml

Example 2.

What's the value and measurement uncertainty in this case?

39.0 ± 0.5 ml



Example 3.

What's the value and measurement uncertainty in this case?

5.67 ± 0.01 g

How to evaluate the accuracy of your results?

➔ **Percentage error:**

$$\text{percentage error} = \left| \frac{\text{literature value} - \text{experimental value}}{\text{literature value}} \right| \cdot 100\%$$

➔ **Percentage error tells you how close you were to the correct value.**

Uncertainty propagation based on the measurement uncertainties

➔ **Absolute uncertainty:**

$$For\ example:\ \ initial\ temperature\ =\ 34.55\ \pm 0.05\ °C$$

➔ **Relative uncertainty:**

$$Relative\ uncertainty\ =\ \frac{Absolute\ uncertainty}{Magnitude\ of\ the\ measurement}$$

➔ **Percentage uncertainty:**

$$Percentage\ uncertainty\ =\ \frac{Absolute\ uncertainty}{Magnitude\ of\ the\ measurement} \cdot 100\ \%$$

Propagation of uncertainty

Uncertainty propagation follows your calculations in the data processing:

If you Add and/or subtract in the data processing:

- ➢ Add the absolute uncertainties

If you Multiply and/or divide in the data processing:

- ➢ Convert to relative / percentage uncertainty
- ➢ Add the relative / percentage uncertainties
- ➢ Convert back to absolute uncertainty

Experimental error based on trials

- *"Uncertainty for average values"*

- ➔ **Experimental error:**

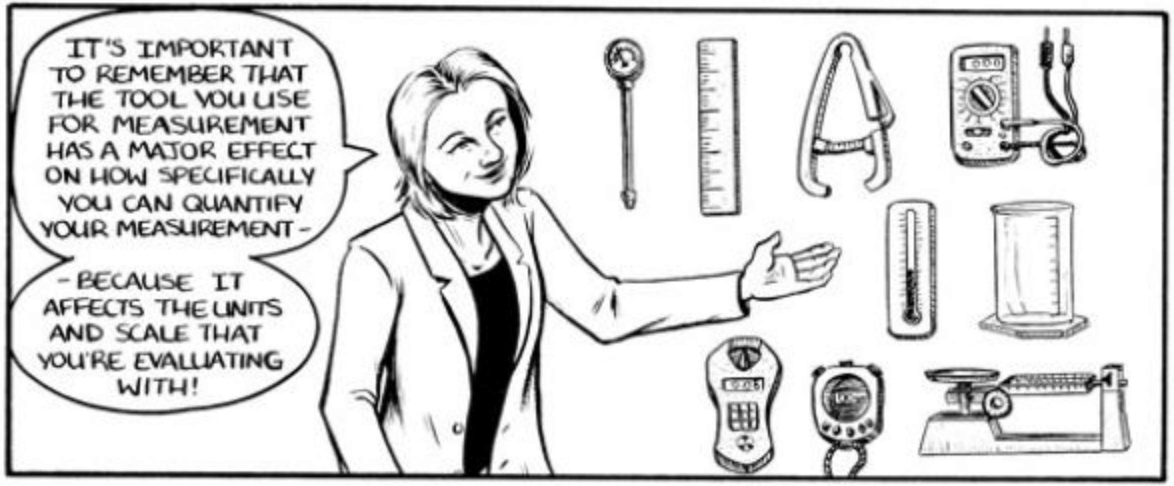
$$\frac{\max - \min}{2}$$

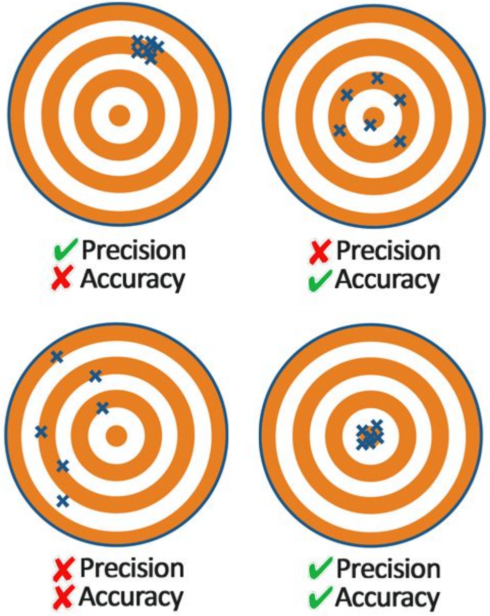
- ➔ **Experimental error tells about the precision of your results.**

Accuracy and precision

Accuracy = How close a measurement is to the true value

Precision = How close replicate measurements are to each other





To reduce uncertainty

- When designing an experiment, choose equipment that reduces the level of uncertainty
    - e.g. measure 100 ml solution with graduated cylinder, not with beaker
- Do experiment many times
    - taking more readings and calculating the average

Example 4.

The following data are collected during a titration.

Final burette reading $= 16.10 \pm 0.05\,\text{cm}^3$

Initial burette reading $= 1.10 \pm 0.05\,\text{cm}^3$

Calculate the percentage uncertainty of the titre. [1

$$percentage\ uncertainty = \frac{uncertainty}{value} \cdot 100\ \%$$

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$$«\frac{0.1\ \text{cm}^3}{15.0\ \text{cm}^3} \times 100 =» \ 0.7\ «\%» \ ✓$$

Example 5.

What is the uncertainty of the concentration of the solution with 2.70 g anhydrous iron(III) chloride, when the uncertainty of the scale is ±0.01 g and the uncertainty of the volume is ±0.001 dm^3? (2.70 grams of the solid compound is dissolved to distilled water and diluted up to 0.500 dm^3 in a volumetric flask)

$$c_{anhydrous}(FeCl_3) = \frac{n(FeCl_3)}{V_{solution}} = \frac{0.016646\ mol}{0.500\ dm^3} = 0.0333\ mol\ dm^3$$

percentage uncertainty of the mass

$$\frac{0.01\ g}{2.70\ g} \times 100\% = 0.37\ \%$$

percentage uncertainty of the volume

$$\frac{0.001 dm^3}{0.500\ dm^3} \times 100\% = 0.20\ \%$$

percentage uncertainty of the concentration

0.37 % + 0.20 % = 0.57 %

Absolute uncertainty of the anhydrous solution is then

$$\frac{0.0333\ mol\ dm^3}{100\ \%} \times 0.57\ \% = 0.00018977, \text{thus}$$

$$c_{anhydrous}(FeCl_3) = 0.0333\ mol\ dm^3 \pm 0.0002\ mol\ dm^3$$