Uncertainty in measurement

- *Any measurements has an uncertainty of at least one unit in the last digit of the reported value*

Examples:

mass of 2.3g has an uncertainty of 0.1 g

mass of 2.294 g has an uncertainty of 0.001 g

A measured volume of 25.2 ml has an uncertainty of at least 0.1 ml (maybe 0.2 if 0.2 is the smallest graduation on the graduated cylinder used for measuring)

- *all the measured digits in a determination including the last uncertain digit are called significant figures*

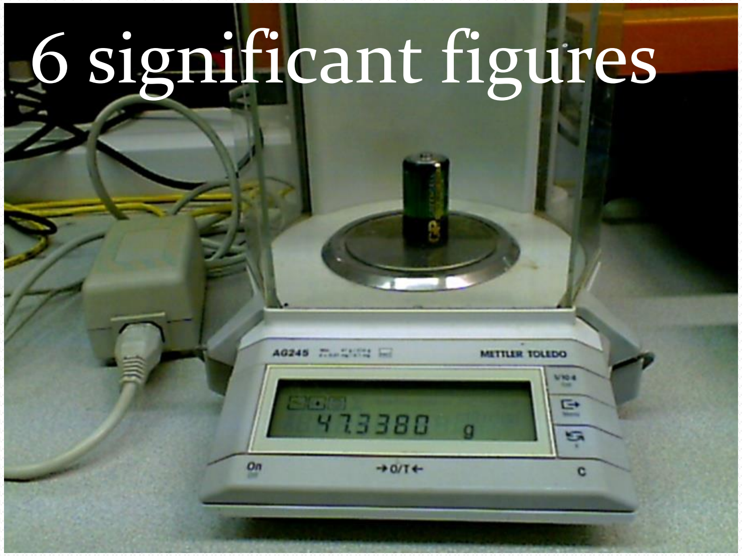
Significant Figures

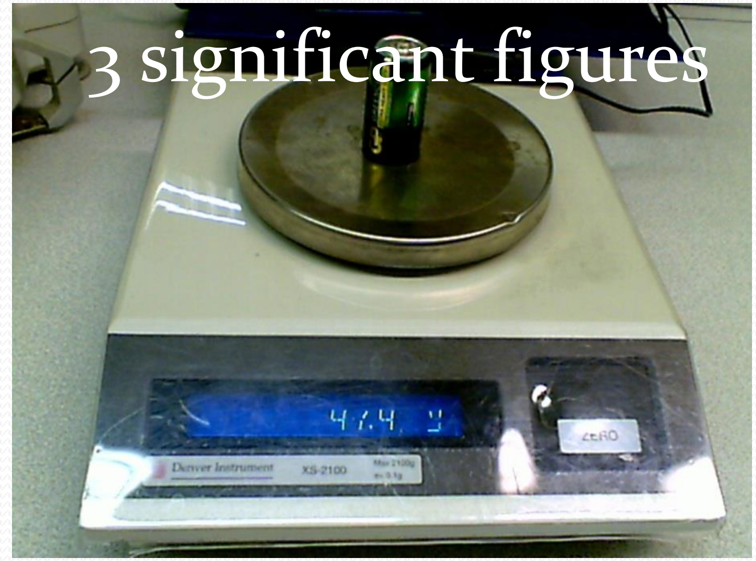
Significant figures come from the graduations/scale on the measuring device.

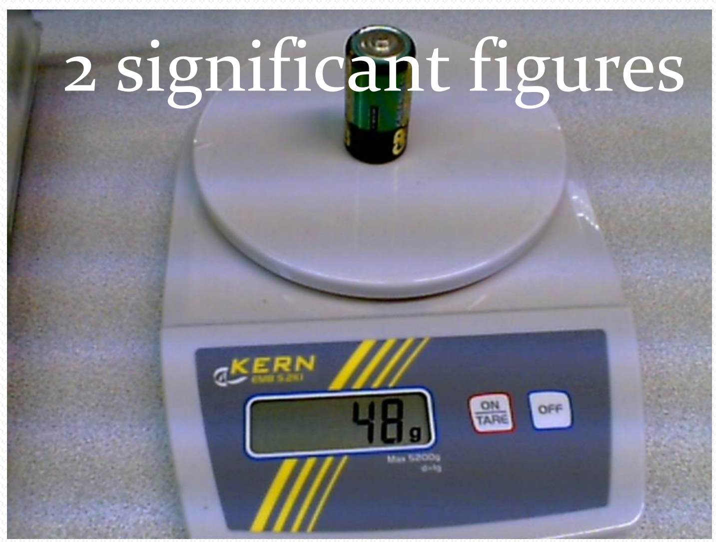
Starting with the first nonzero digit on the left, count this digit and all remaining digits to the right

this is the number of significant figures

- **Examples:**
- 1267 m has 4 significant figures
- 55.0g has 3 significant figures
- 70.607 mL has 5 significant figures
- 0.00832407 s has 6 significant figures


6 significant figures
AG245
METTLER TOLEDO
47.3380 g
On
→0/T←


3 significant figures
47.4 g
ZERO
Denver Instrument
XS-2100


2 significant figures
KERN
48 g
ON
TARE
OFF

Significant Figures….

- *The number of significant figures can be uncertain in a number that ends with a zero to the left of where the decimal place would fall* e.g. 1300 g

- Using scientific notation is best (less ambiguity) e.g.:

  1.3×10^3 g (2 significant figures), 1.30×10^3 g (three significant figures) or 1.300×10^3 (four significant figures)

- <u>we assume all zeros written down are significant</u>

Rules for rounding numbers

Results calculated from a measurement are as uncertain as the measurement itself

- when adding or subtracting numbers we round to the same number of decimal places as the number with the least number of decimal places
- when multiplying or dividing we round to the same number of significant figures as the number with the least number of significant figures

Rules for rounding numbers

- when rounding numbers - if the leftmost digit to be dropped is less than 5 we do not change the remaining digits (for two significant figures 3.4456 rounds to 3.4)

- if the leftmost digit to be dropped is greater than 5 we increase the last digit by 1 (for three s.d 23.387 and 23.3511 round to 23.4)

- *Examples*

(a) Add 1.0023 g and 4.383 g = 5.385 (3 decimal places)

(b) Subtract 421.23 from 486 g

= 64.77 g = 65 g (no decimal places)

Rules for rounding numbers

- *Example*

(a) Multiply 0.6238 cm by 6.6 cm

4.1 cm^2 (2 significant digits)

(b) Divide 421.23 g by 486 ml

0.867 g/ml (3 significant digits)

- *Example*

A bathtub is 13.44 dm long, 5.920 dm wide and 2.54 dm deep. Calculate its volume in Litres

V = l x w x d = 13.44 dm x 5.920 dm x 2.54 dm

= 202 dm^3 or 202 L

Precision and Accuracy in Measurement

Precision

reproducibility - a measurement is precise if it is close to other values obtained by repeating the determination using the same procedure

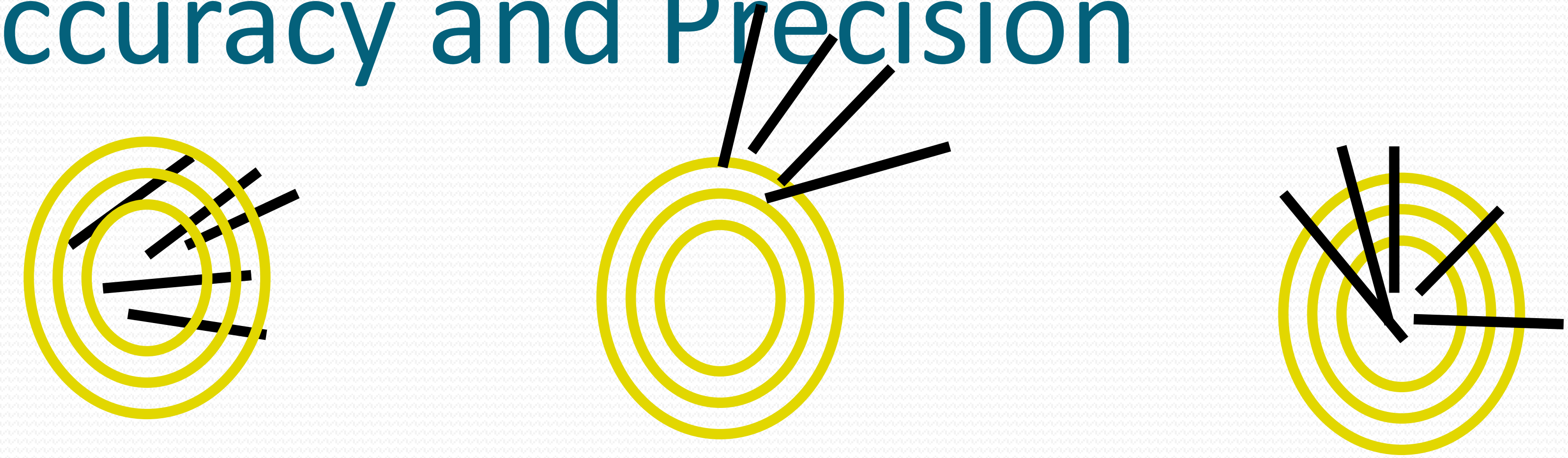
Accuracy

correctness - a measurement is accurate if it is close to the true (correct) value.

Error

anything that causes a measurement to differ from the true value or the amount that it differs

Accuracy and Precision



good accuracy
poor precision

poor accuracy
good precision

good accuracy
good precision

Measurement Error

Error = measured value - true value

- Error can be:
  - negative

  (if measured value lower than true value)
  - positive

  (if measured value lower than true value)

<u>We report error as a percentage:</u>

% error = (error / true value) x 100

Measurement Error

- Example: in an experiment to meaure gravity using a simple pendulum, g was measured to be 10.14m/s². The true value for g is 9.81m/s². Calculate the error and %error.
  - Error = measured – true = 10.14-9.81 = 0.33m/s²
  - %error = (error/true)*100 = (0.33/9.81)*100 = 3.4%

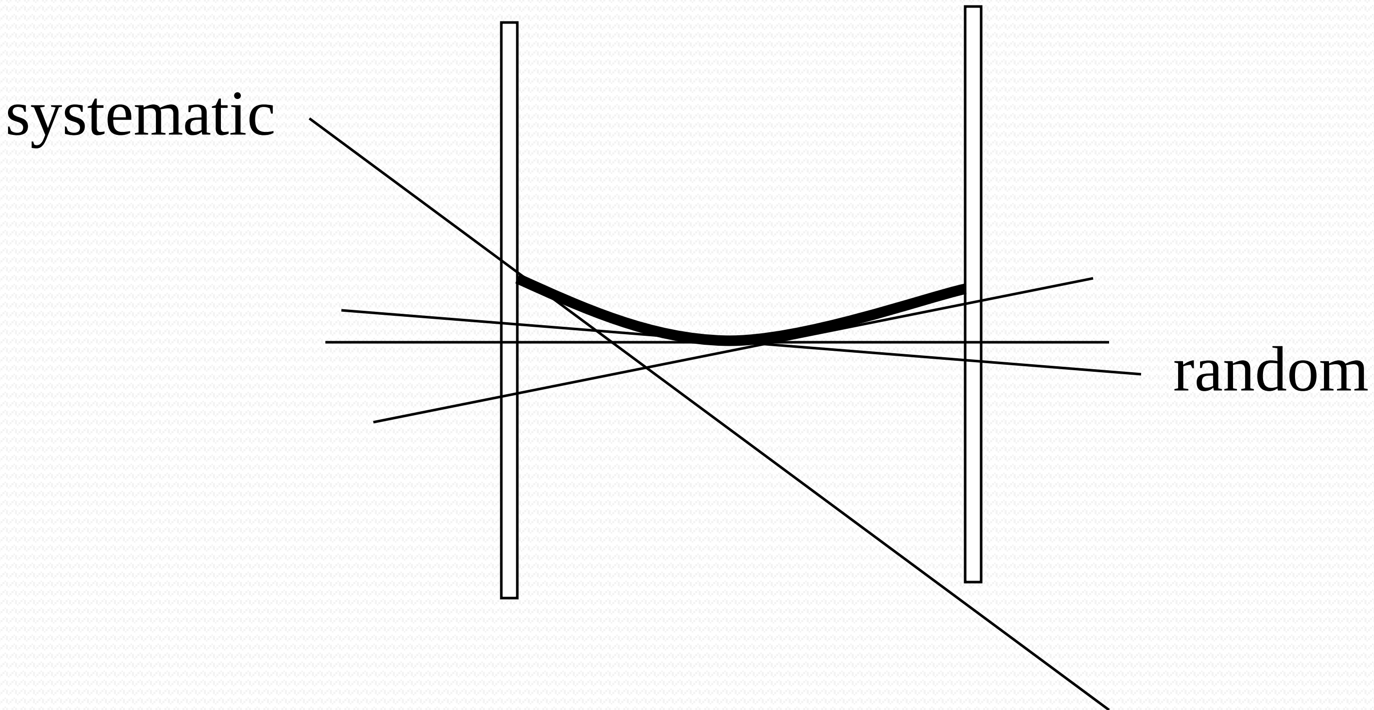
Random and Systematic Error

Random Error

- Errors that produce a set of values that differ from one another by random amounts (affects the **precision** of a result
- Due to:
  - limitation of scale (least count) on instrument,
  - Parallax error in reading from scale
  - Difficulty in estimating a meniscus position of liquid in a graduated cylinder

Error involved in Reading Meniscus

- the meniscus appears at different heights as the viewing angle changes
- should be viewed exactly horizontally



Random and Systematic Error

Systematic Error

- errors that produce a result that differs from the true value by a fixed amount (affects **<u>accuracy</u>** of result)
- Due to ‘off-sets’ on instruments or from a consistently incorrect method of reading an instrument.
- e.g. a micrometer with a zero error; poorly calibrated pH meter that reads 0.5 units lower than the true value

Precision: Mean Value and Range

A measurement is often repeated, several times, in order to reduce the uncertainty.

- **The Mean:**

  This is the average value. It is the reported value for a measurement when several reading have been taken.

- **The Range:**

  This is the difference between the highest and the lowest value.

  A large range implies poor precision;

  A small range implies good precision.

Find the mean and the range for student A and student B who each made 5 independent readings of a volume of reagent (ml)

A	3.42, 3.43, 3.41, 3.44, 3.41		
B	3.67, 3.65, 3.64, 3.68, 3.65		
	Which result is more precise?		

Find the mean and the % error for student A and student B who each made 5 independent readings of a volume of 3.42 ml of reagent

A	3.42, 3.43, 3.41, 3.44, 3.41		
B	3.67, 3.65, 3.64, 3.68, 3.65		
	Which result is more accurate?		

Find the mean, range and the % error for student A and student B who each made 5 independent readings of a volume of 3.42 ml of reagent

A	3.5, 3.3, 3.4, 3.3, 3.4			
B	4.2, 4.1, 4.3, 4.3, 4.1			
	Which result is more accurate? Which result is more precise?			

True Values

- The true value must be known if we are to calculate error
- True value also required for instrument calibration
- For experiments whose purpose is to measure a physical constant it is usually possible to find an accepted value in the literature (Handbook of Chemical and Physical Constants)
- Determination of the accuracy of a measurement requires calibration of the analytical method with a known standard.

Contrasting precise and accurate measurements

a measurement is

precise | accurate

if it in agreement with

repeated measurements by the same procedure | the true value

in other words it is

Reproducible | correct

the extent of agreement can be expressed as the

Range in values of repeated measurements | Absolute error or percent error of the measurement

Contrasting Random and Systematic Errors

An error in measurement can occur

inconsistently	consistently

in which case it is classified as

random	systematic

and it causes poor

precision	accuracy

the effect of the error can be reduced to

Repeating the measurement and averaging the results	Running a standard and applying a correction factor

Exercise (Part I)

On the table there are five values obtained by experimenter A from repeated measurements of the concentration of a reagent.

(a) What is the mean?
(b) What is the range?
(c) If the correct value is 81.50 ppm, what is the percentage error?

Concentration (ppm)
79.94
80.36
81.00
79.45
80.62

Exercise (Part II)

On the table there are five values obtained by experimenter B for the concentration of the same reagent (as in Part I).

(a) What is the mean?
(b) What is the range?
(c) What is the percentage error?
(d) Which, A or B, has the more accurate result?
(e) Which, A or B, has the better precision?

Concentration (ppm)
80.94
79.60
81.22
81.68
81.80