# Lab 1 – Measurements

## Accuracy

- How closely a measurement/calculation conforms to the correct value

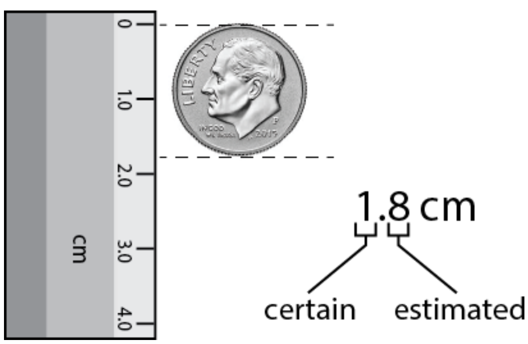
## Precision

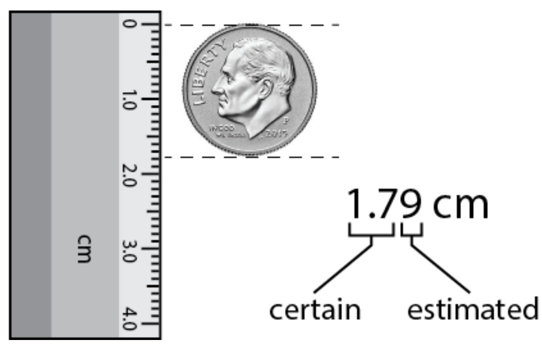
- The degree of 'exactness' in your measurement. Below, we will see how this is related to certain versus estimated digits and significant figures.

***Some examples of accuracy versus precision are given on page 4***

### Certain vs Estimated Digits

When we make a measurement, some part of the measured value will be known with certainty, and some part will be estimated. Let's look at an example:




Here we are measuring a dime with 2 different rulers. The left-hand side ruler only has markings at every centimeter. The right-hand side ruler is more precise, it has markings every 0.1 cm.

Using the left-hand side ruler, we have to estimate the distance between each whole centimeter. When we measure the dime, we are *certain* its diameter is between 1 and 2 cm, but we have to *estimate* how far between these values the edge of the coin is.

Using the right-hand side ruler, we are *certain* that the diameter is between 1.7 and 1.8 cm. This time, we *estimate* where the edge of the coin lies between these values. This gives us a value of 1.79 cm. This measurement is 10 times more precise than using the left-hand side rule.

### Significant Figures

- The significant figures given in a value reflect the degree of precision in a measurement or calculation.

When we make a measurement, the last significant figure in the value is also the estimated digit in the measurement.

There are some rules about how many significant figures we should use when doing measurements and calculations. Throughout this course, we will try to use the correct number of significant figures when recording our measurements and writing the answer to any calculations.

Some rules to remember are:

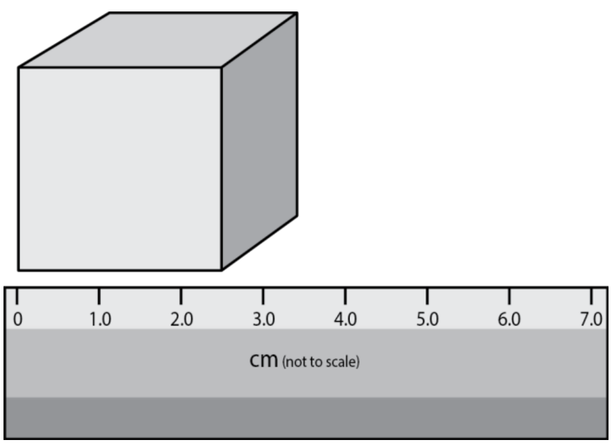
- **Non-zero digits are always significant.**
- **Zeros that are between two significant digits are always significant.**
- **Zeros that come before the first non-zero digit are not significant.**
- **Trailing zeros are only significant if they are to the right of the decimal point.**

Let's look at some examples:

In each of the following values, the significant digits are underlined.

| | |
|---|---|
| 12600 | Has 3 significant figures (s.f.). The trailing zeros are not significant. |
| 72.40006 | Has 7 s.f. The zeros are significant because they are between non-zero digits. |
| 0.005 | Has 1 s.f. The zeros before the 5 are not significant. |
| 0.00600 | Has 3 s.f. The trailing zeros are to the right of the decimal point, so they are significant. |

Now, let's imagine we are going to calculate the volume (V) of a wooden cube. First, we need to measure the length of one of the cube's edges with a ruler:




The edge of the cube is recorded as 2.5 cm long. This value has 2 s.f. When we do calculations with values we've measured, we always round the answer to the same number of significant figures as the measurement. First, let's do the calculation:

V = volume of the cube

L = length of a cube edge

$V \text{(for a cube)} = L^3$

$V = 2.5^3 = 15.625 \text{ cm}^3$

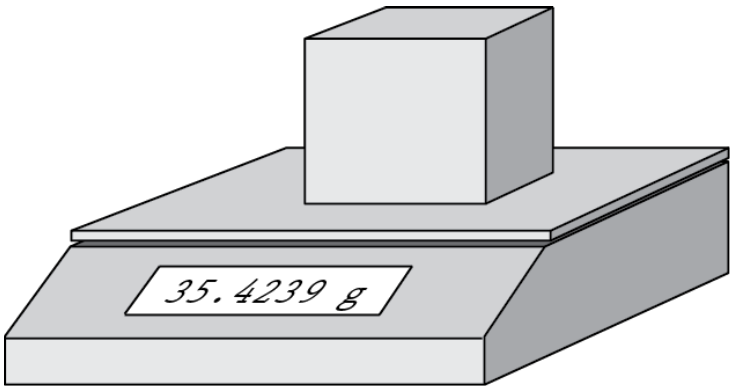
The value $15.625 \text{ cm}^3$ has 5 s.f. but our measurement only has 2 s.f. So, we need to round the answer to 2 s.f. To do this, we look at the $3^{rd}$ significant figure, which is a 6. Because the value is greater than 5, we round upward. This gives the volume of the cube to 2 significant figures:

$V = 16 \text{ cm}^3$

This value properly reflects the precision of our initial measurement.

Sometimes, we need to calculate a value where the measurements have been recorded to different numbers of significant figures. In these cases, we always round to the number of significant figures as the measurement with the *least* number of significant figures.

For example, let's assume we want to calculate the density of the cube ($\rho$) in the last example. To do this, we need to know the mass (m) of the cube and its volume. We already know that the volume of the cube is 16 $cm^3$. To find the mass, we use a very precise balance:




The balance gives us a value of 35.4239 g for the mass of the cube. This value has 6 significant figures.

Now let's calculate the density:

$$\rho = m/V = 35.4239/16$$

$$\rho = 2.21399375 \text{ g/cm}^3$$

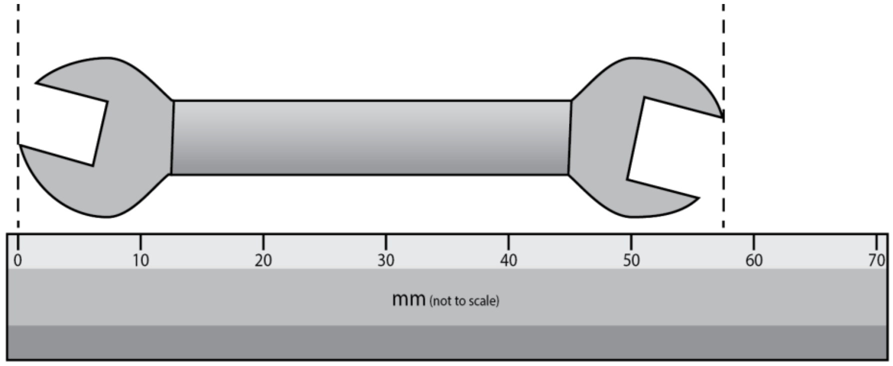
This value for the density has too many significant figures.

Our measurement for the volume has the least number of significant figures (2 s.f.) so that is the number of significant figures our calculated density should have:

$$\rho = 2.2 \text{ g/cm}^3$$

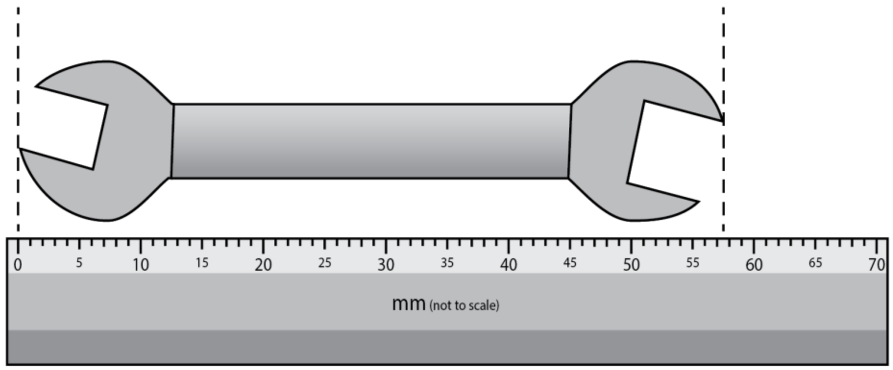
This time, we round the answer down, because the 3rd significant figure is less than 5. Our final value for the density with 2 s.f. reflects the precision of our initial measurements.

## Accuracy vs Precision Examples (estimated digits are underlined)




Ruler #1

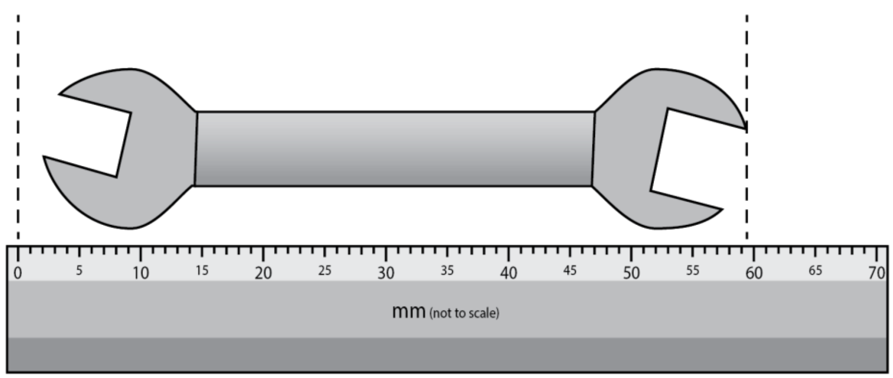
The smallest division on this ruler is 10 mm. The actual length of the spanner is 57.5 mm exactly. Using ruler #1 to measure the spanner it is hard to judge the length any better than to the nearest mm. We record a measurement of 58 mm.




Ruler #2

The smallest division on ruler #2 is 1 mm. If we now use ruler #2 to measure the spanner we can see that it lies exactly between the 57 mm and 58 mm divisions. So, we can confidently record a measurement of 57.5 mm.

If we compare the measurements made with the two rulers: 58 mm and 57.5 mm, we can see that the measurement made with ruler #2 is both *more accurate* (closer to the real length of the spanner) and *more precise* (recorded to more significant figures).




Ruler #2

Many instruments will allow you to record a precise measurement, even if that measurement is not accurate. Let's imagine you measure the spanner with ruler #2, but don't carefully line up the end of the spanner with the zero mark. In this case, you record a precise measurement of 59.5 mm, however, this is several mm longer than the real length of the ruler. This measurement is *not* accurate, even though it is precise.

## Exercise

You will each have access to several wooden blocks and an irregularly shaped piece of metal. Perform the following measurements using these objects:

1. **Cuboid block:** Measure the length, width, and height of the block. Repeat each measurement 3 times and then calculate the average. Once you have calculated the average for each measurement, calculate the volume of the block. Record all of your measurements.

To calculate the volume of the block, use the following formula:

volume (cuboid) = height x width x length

**remember to add the correct units to your measured lengths (e.g., cm or mm) and calculated volume (e.g.. $cm^3$ or $mm^3$).

2. **Cylindrical Block:** Measure the radius and height of the cylinder. Repeat each measurement 3 times and then calculate the average. Once you have calculated the average for each measurement, calculate the volume of the cylinder. Record all of your measurements.

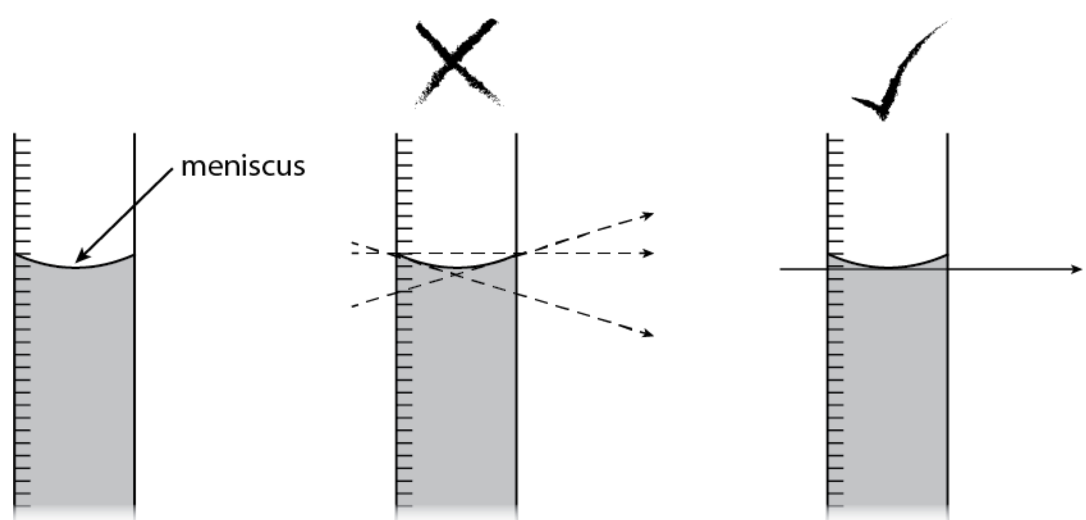
To calculate the volume of the cylinder, use the following formula:

volume (cylinder) = $\pi$ x radius$^2$ x height

3. **Irregular Metal Piece:** Determine the volume of the irregular metal piece by measuring the volume of water it displaces.

A) Take a graduated cylinder and fill it with enough water that the metal piece can be completely submerged.

B) Record the volume of water in the graduated cylinder. Make sure that you record the value at the correct point of the meniscus:



C) Now insert the irregular metal piece and record the volume again on the graduated cylinder. Subtract the 1st measurement from the 2nd to give you the volume of the irregular metal piece.

D) Remove the metal piece and repeat steps B and C until you have measured the volume of the piece 3 times. Use these 3 measurements to calculate an average volume.

4. Weight: Take the cuboid wooden block. Zero (tare) the scale. Place the block on the scale (also called a balance) and record the weight that is displayed. Remember to include the correct units. Repeat the measurement 3 times and calculate an average weight for the block.

For each measurement of the weight, record which digits are certain and which are estimated.

**Helpful Info:**

- You might find it useful to indicate for all of your measurements which are the certain digits and which are the estimated digits. This is an important concept to remember throughout the course.

- To calculate an average (specifically the arithmetic mean) we add together our different measurements, then divide by the number of measurements we have made. Our symbols will be:

$n$ = number of measurements

$x_1, x_2, x_3 \ldots x_n$ = the individual measurements

$\bar{x}$ = the mean

For this exercise, we will always have 3 measurements ($n$ = 3), so the formula will be:

$$\bar{x} = \frac{x_1 + x_2 + x_3}{3}$$

More generally (i.e., for any number of measurements), this formula can be written as:

$$\bar{x} = \frac{\sum_1^n x}{n}$$