Topic 1 - Measurements and Uncertainties

Orders of magnitude

In physics, we deal with a wide range of magnitudes. We use tiny values such as the mass of an electron and huge ones such as the mass of the observable universe. To easily understand the magnitude of these quantities, we need a way to express them in a simple form. To do this, we simply write them to the nearest power of ten (rounding up or down as appropriate).

That is, instead of writing a number such as 10000, we write 10^4 .

Orders of magnitude are used to get an idea of the scale and differences in scale between values. It is not an accurate representation of a value. For example, if we take 300, it's order of magnitude is 10^2 , which when we calculate it gives 10 x 10 = 100. Although this is three times less than the actual value, the point of orders of magnitude is to get a sense of the scale of the number ('ball park'), in this case we know the number is within the 100's.

The ranges of magnitudes of quantities that occur in the Universe (smallest to largest):

Masses:

- mass of electron: 10^{-30} kg
- mass of universe: 10^{+50} kg

Distances:

- nucleons (protons, neutrons): 10^{-15} m
- size of the visible universe: 10^{+25} m

Times:

- light to pass across a nucleus: 10^{-23} s
- age of the universe: 10^{+18} s

Ratios of quantities as differences of orders of magnitude:

Using orders of magnitude makes it easy to compare quantities. For example, if we want to compare the size of an atom (10^{-10} m) to the size of a single proton (10^{-15} m), we would take the difference between them to obtain the ratio. Here, the difference is of magnitude 10^5 meaning that an atom is 10^5 or 100000 times bigger than a proton.

Estimating approximate values of everyday quantities:

Significant figures
To express a value to a certain number of significant figures means to arrange the value so that it contains only a certain number of digits which contribute to its precision.

For example, to state the value of an equation to three significant figures given a value of 3.7123, we would state it as 3.71.

Note that 3.71 is accurate to three significant figures as we count both the digits before and after the point.

The number of significant figures includes all digits except leading and trailing zeros (such as **0.00**35 (2 sig. figures) and 35**000** (2 sig. figures)) which serve only to indicate the scale of the number.

Rules for identifying significant figures:

- All non-zero digits are considered significant, such as 16 (2 sig. figures) and 16.34 (4 sig. figures).
- Zeros placed in between two non-zero digits are significant, such as 2**0**5 (3 sig. figures) and 2**00**4 (4 sig. figures).
- Trailing zeros in a number containing a decimal point are significant (such as 6.54**00** (5 sig. figures) note that a number 0.000**12300** also has 5 sig. figures as the leading zeros are not significant).

Calculated values should not be stated to a greater accuracy than that of the original data, nor should measurements be reported to a greater precision than the equipment used to obtain them supports.

Expressing significant figures as orders of magnitude:
To represent a number using only the significant digits can easily be done by expressing it's order of magnitude. This removes all leading and trailing zeros which are not significant.

For example:
0.000**34** contains two significant figures (34) and four leading zeros in order to show the magnitude. This can be represented so that it is easier to read as such: 3.4×10^{-4} .

Note that we simply removed the leading zeros and multiplied the number we got by 10 to the power of negative the amount of leading zeros (in this case 4). The negative sign in the power shows that the zeros are leading.

A number such as **34**000 (2 s.f.) would be represented as 34×10^{3} .

Again, we simply take out the trailing zeros, and multiply the number by 10 to the power of the number of zeros (3 in this case).

There are a couple of cases where you need to be careful:

- A number such as 0.004500 would be represented as 4.500×10^{-3} . Remember, trailing zeros after a decimal point **are** significant.
- 57000 (3 s.f.) would be represented as 570×10^{2} . This is because it is stated that the number is accurate the 3 significant zeros, therefore the first trailing zero is significant and must be included. Note that this can be used as another way to express a value such as 56000 to three significant figures (as opposed to writing "56000 (3 s.f.)").

Rounding

When working with significant figures you will often have to round numbers in order to express them to the appropriate number of significant figures.

For example:
State 2.342 to three significant figures would be written 2.34.

When representing the number 2.342 to three significant figures we rounded it down to 2.34. This means that when we removed the excess digit, it was not high enough to affect the last digit that we kept.

Whether to round up or down:
If the first digit in the excess which is being cut off is 5 or higher, we increase the last digit that we are keeping (and the rest of the number if required). If the first digit in the excess being cut off is lower than 5, we do not change the last digit which we are keeping.