## Significant Figures

There is no such thing as an EXACT MEASUREMENT. So it is important to have a way of estimating the degree of inexactness of a measurement. One way is to carry only as many significant figures as are justified by the measurement or the calculation. The uncertainty of a measurement or a calculation is expressed in the digit that is farthest to the right.
6.14 cm . The 6 and 1 are exact; the 4 is inexact. The correct number might be $6.15,6.16$ or 6.11 . We don't exactly know. All we know is that the real number is probably somewhere between 6.13 and 6.15 .

In calculations, the rule is that you carry all the digits to the end of the calculation and then and only then do you round the final answer to the appropriate number of sigfigs. And that number is limited by the number of sigfigs in the least precise term of the calculation.

Interpolation means reading between the lines. A graduated cylinder might have an etched line for every 0.1 mL . But your eyes might be able to detect a difference between, say, 7.1 mL and 7.2 mL . Your might be able to read the volume to the nearest 0.05 mL or the nearest 0.02 mL , depending on how good your eyes are. So you might report $7.12,7.15$ or 7.20 mL , depending on what you see. The last digit to the right represents the uncertainty in what you are able to read. The value you report contains 3 significant figures. Note the difference between 7.1 mL and 7.10 mL . The first indicates a imprecision of perhaps one part in 70 . The second indicates an imprecision of about one part in 700 - quite a difference!

If you are confident that you can read the cylinder to the nearest 0.05 mL , then you might also report you reading in this way: $7.15 \pm 0.05 \mathrm{~mL}$, thus showing that you are confident that the exact number lies within the range of 7.10 mL to 7.20 mL .

Percent deviation from the mean. It is likely that measuring the physical property of a substance several times will give different results. Let's say you measure the density of an unknown two times and get results of $6.55 \mathrm{~g} / \mathrm{mL}$ and $6.81 \mathrm{~g} / \mathrm{mL}$. The value you will report is the average of the two values, 6.68 $\mathrm{g} / \mathrm{mL}$, accompanied by the percent deviation from the mean. This is given by the formula,

Difference between the two results divided by the average x 100
So the result you report is $6.68 \mathrm{~g} / \mathrm{mL}$ and the percent deviation is $(0.26 / 6.68) \times 100=3.9 \%$ ( 2 sigfigs).
If you obtain multiple readings, then the average of the deviations from the mean is divided by the average $\times 100$.

Percent error applies when the true value (as listed in a standard reference such as The Handbook of Chemistry and Physics) is known. This is given by the following equation:

$$
100 \mathrm{x} \text { [Experimental value - "true value"] divided by the "true value" }
$$

Say that the true value in our above example is $7.40 \mathrm{~g} / \mathrm{mL}$. Then the percent error is

$$
100 \times[6.68-7.40] / 7.40=9.7 \% \text { (always a positive number) }
$$

Only two significant figures are permitted in the percent error because the least accurate term in the above equation has just two: $7.40-6.68=0.72$ ).

Scientific notation. Some numbers are ambiguous as to number of significant figures. A result like 100 g could mean $\pm 1 \mathrm{~g}$ or $\pm 10 \mathrm{~g}$. Scientific notation is used not only to express very large or very small numbers but also to avoid this ambiguity.

If the precision is to the nearest $1 \%$, then the mumber is expressed as $1.00 \times 10^{2}$. But if the precsion is only to the nearest $10 \%$, then it would be $1.0 \times 10^{2}$. In other words, the first number has three sigfigs, while the second less precise number has only two sigfigs.

## Precision vs accuracy.

The average deviation from the mean expresses precision, that is, the repeatability of you measurements. The percent error expresses that accuracy of the measurement compared to a reference standard.

A measurement may be very precise yet very inaccurate. Another measurement may be very accurate yet very imprecise.

Examples:
Very precise, very inaccurate: deviation from the mean $=1.0 \%$, percent error $=30 \%$.
Very accurate, very imprecise: deviation from the mean $=30 \%$, percent error $=1.0 \%$.

