# APPENDIX A

## ACCURACY, PRECISION, ERRORS, UNCERTAINTY, ETC.

In common speech, the words accuracy and precision are often used interchangeably. However, many scientists like to make a distinction between the meanings of the two words. Accuracy refers to the relationship between a measured quantity and the real value of that quantity. The accuracy of a single measurement can be defined as the difference between the measured value and the true value of the quantity. The accuracy of a measurement is therefore limited by such things as the calibration and sensitivity of the instruments used, your ability to read the meters, mistakes in recording the numbers, and so on.

The word precision refers to the amount scatter in a series of measurements of the same quantity. It is possible for a measurement to be very precise, but at the same time not very accurate. For example, if you measure a voltage using a digital voltmeter that is incorrectly calibrated the answer will be precise (repeated measurements will give essentially the same result to several decimal places) but inaccurate (all of the measurements will be wrong). By making a series of measurements of some quantity, we can obtain an estimate of the precision of each individual measurement. The example discussed below illustrates how this works.

The words error and uncertainty are also often used interchangeably. Nevertheless, it is important to be aware of the distinction between the actual error in a given measurement (i.e. in the amount by which the measured value differs from the true value) and the uncertainty in a measurement. The point is that in many experiments we do not know the true value of the quantity we are measuring, and therefore cannot determine the actual error in our result. However, it is still possible to make an estimate of the uncertainty (or the probable error) in the measurement based on what we know about the properties of the measuring, instruments, etc.

The following example illustrates several of these ideas. In this example the resistance of a known $1000 \pm 0.01\ \Omega$ resistor is determined by measuring V and I for several different voltage settings. The results are given in the table on the following page. The average value of R in this example is 1002.4 $\Omega$, so our final result has an error of 2.4 $\Omega$. The precision of any individual measurement of R can be determined by calculating the standard deviation:

$$s \equiv \frac{1}{N-1}\left[\sum_{i=1}^{N}\left(x_i - \overline{x}\right)^2\right]^{1/2}$$

where $\overline{x}$ is the average value of x and where N is the number of measurements. In this example the standard deviation is 5.6 $\Omega$. We could take this as an estimate of the uncertainty or probable error, since any individual measurement has a reasonable probability of being in error by at least that amount. It should be emphasized, however, that the actual error in a measurement can be much larger than the standard deviation if there are systematic errors (for example errors in the calibration of some meter) that affect all the measurements the same way.

**Data for a 1000 ± 0.01 kW Resistor**

| V(a) (volts) | I(b) (mA) | R(c) (W) |
|---|---|---|
| 1.000 | 0.99 | 1010 |
| 2.000 | 1.99 | 1005 |
| 3.000 | 3.00 | 1000 |
| 4.000 | 4.02 | 995 |
| 5.000 | 4.99 | 1002 |

Average = 1002.4
Standard Deviation = 5.6
Error = 2.4
% Error = 0.24 %

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(a) Measured with digital voltmeter.
(b) Measured with Simpson VOM.
(c) Calculated from R = V/I.

Whenever possible measured values of quantities should be compared with given or theoretical values and the percent error given. In some of the experiments you will be asked to make detailed calculations of the uncertainties in your measurements. Although this is usually not required (since the calculations are often long and time consuming), it is always important for experimenters to be aware of potential sources of error.