ERROR ANALYSIS IN CHEMISTRY EXPERIMENTS

In order to discuss discrepancies between experimental and expected results, as well as possible errors that can lead to poor results, one should have some knowledge of how errors may arise.

In every chemistry experiment there is some source of error involved. These errors can be classified as environmental, instrumental, and procedure errors. Although these errors cannot be totally eliminated, they can be reduced to give a minimal effect on the experiment.

Environmental errors are those due to the conditions in the laboratory such as temperature, relative humidity, and atmospheric pressure. Since these conditions cannot be tailored to suit the needs of any one experiment, they can either be reduced by using correction factors or they can be neglected by assuming the basic principles behind the experiment to be true. For example, the density of water is 1.000 gram/cm^3 at 760 mm Hg and 4.0°C, but it varies as the temperature and pressure vary. Generally, for most experiments, the error introduced by assuming the density of water is constant at 1.000 gram/cm^3, even though the pressure may be 770 mm Hg and the temperature 25°C, is quite small and is usually neglected. In the case where water is being used to calibrate the volume of a container, for example, the small variation of density cannot be ignored.

Instrumental errors are those errors due to uncertainties or minor defects in the instruments used in an experiment such as a balance, a graduated cylinder, a thermometer, etc. Such errors usually are confined within a range of ± one graduation on the measuring device. These errors can, in many cases, be reduced or corrected for by calibrating the instrument before using it with known "standards". If standards are not available, one can perform a calibration, of sorts, by taking three or more independent and objective readings and using the average value of these readings in the experimental data and calculations. Such calibrations, however, take more time than they may be worth for routine work so these errors can be dealt with simply by using the same measuring device for the entire experimental procedure. This does not remove the error, but it is assumed that the error will remain constant throughout the experiment and will not have any major effect on the final results. For example, a graduated cylinder will hold 25 mL of water at 20°C, but at 25°C, the volume of water will be slightly different. Ignoring this error does not eliminate it, but since the small variation in volume is consistent throughout the experiment, it should not result in a large error in the results.

Another method of reducing an instrumental error can be illustrated by the method known as "weighing by difference". For example, suppose you have to weigh out a 2.50 gram sample of a substance for an experiment. You could weigh the sample directly on the balance, but the balance may give you an erroneous weight for such a small mass. In weighing by difference, it is assumed that the error in the balance is consistent over the range being used. You would first weigh the container of the substance being used. Next, remove a small amount of substance and weigh the container again. Continue with this operation until the container of substance is about 2.50 grams lighter in mass. Although the total masses on the balance may be in error, the difference between any two masses should not contain the error. In a similar fashion, you could place a container such as a small beaker on the balance, determine its weight, then, add the substance until the mass has increased by 2.50 grams.

Procedure errors are those errors due to the experimental procedure and "human" errors. No procedure is perfect. Since any experimental procedure is written in general terms, there will always be exceptions which will not perform as expected. These errors must be accounted for, sometimes by changing the procedure to fit these exceptions, and sometimes by stating that these exceptions could not be dealt with. It is common to make notations in the laboratory notebook or laboratory report giving logical and reasonable suggestions for dealing with them in future procedures. An example of a procedure error is loss of some of the product of a preparation as a result of material sticking to the sides of the container after transferring the substance to a new container.

Another procedure error is poor results due to sloppy laboratory technique and procedure. Such errors should be accounted for in your error discussion. (Do not be afraid to admit you made a mistake.)

In addition to the errors discussed above, any assumptions made in the experiment, such as the ideal behavior of an ideal gas, must be accounted for in the error analysis.

ERROR ANALYSIS AND SIGNIFICANT FIGURES

The results of scientific experimentation are usually expressed in numbers. When reporting such numerical results, or data, the experimenter should be concerned with the following:

(a) What is the best value of the measured quantity
(b) What is the uncertainty in this best value

In the evaluation of quantitative data, the terms **accuracy** and **precision** are commonly used.

Accuracy describes the difference between an observed or experimental value and the true or accepted value. Accuracy is important in measurement experiments where a value such as a molecular weight or a density are determined. Accuracy is often reported as the percent error when evaluating experimental results.

Precision describes, for a set of measurements on the same quantity, the differences among the individual measurements. This is sometimes referred to as the reproducibility of a measurement. If the values are close together, then the precision is high. If the values are scattered, then the precision is low. For a measuring device, the precision may be expressed as the uncertainty of the device. (See Table E-1) When evaluating experimental results the precision can be expressed as the maximum uncertainty, the average deviation, or the standard deviation.

Accuracy and precision do not always go together. It is possible for a single measurement to be very accurate, but for a series of measurements to be scattered around the accepted value. Also, a series of measurements could be very precise, but none of the values may be accurate.

When reporting the value of a measured quantity, the measurement should be reported to the precision to which it was made. Values should not be rounded off nor should any zeros at the end of the measured value be omitted. Rounding off of final values or results and the number of significant figures depend on the individual measurements used in calculation of the results.

Table E-1. The precision associated with various pieces of equipment used in the laboratory. These uncertainties express limitations in the reading of the instrument and do not reflect "systematic" errors.

Instrument	Typical Uncertainty
Triple-beam (centigram) balance	±0.01 g
Top-loading electronic (milligram) balance	±0.001 g
Analytical balance (four place)	±0.0001 g
100 mL graduated cylinder	±0.5 mL
10 mL graduated cylinder	±0.1 mL
50 mL buret (0.1 mL graduations)	±0.05 mL
25 mL buret (0.1 mL graduations)	±0.025 mL
10 mL transfer pipet	±0.02 mL
Thermometer (graduated to 1°C)	±1.0°C