Physics 11/12 - Sources of Experimental Error

(Uncertainty in measurement)

Analysis of "error" and limitations of measurement is a **very important** part of any scientific study. "Sources of Error" are factors (causes) that may limit the accuracy and/or the precision of experimental results.

Sources of error are factors inherent within the experimental set-up and procedures that cannot be "fixed", no matter how hard you try. For example, if your experiment is intended to determine the acceleration due to gravity of a freely falling object, the effect of air resistance will be one of the "sources of error". You can reduce the effects of air resistance by dropping an object that is highly streamline, but unless you have the appropriate equipment to create a vacuum by removing all the air you cannot completely eliminate the effect of air resistance.

When listing "Sources of Error" in your lab write-up:

- Give **SPECIFIC** examples of sources of error, and describe their probable effect on your results. Some examples that relate to specific labs:
    - The ruler scale is limited to measure to 1 mm
    - The effects of friction between the ticker tape and the recording timer were not accounted for
    - The dots created by the spark timer appear slightly smudged and are difficult to see
    - The dots created by the spark timer do not appear to be in a perfectly straight line, indicating that the falling mass may have been swinging rather than falling straight down
    - Example of how to express a source or error in a sentence: "*Air resistance acting on the falling object may have decreased the acceleration rate, producing experimental results lower than the accepted value for acceleration due to gravity*"

- DO NOT use the term "*human error*" to describe sources of error. That term is too vague. If you are referring to limitations of the human body, state those limitations specifically. For example:
    - The limits of hand-eye-coordination when drawing a line of best fit on the graph
    - The limits of human reaction time when using the stopwatch
    - The limits of human eyesight in discerning the location of the centre of the dot created by the spark timer

- Your list of *sources of error* must **NOT** include "mistakes" (e.g. calculation errors, or performing the lab incorrectly). If you think you may have made a mistake in measurement or calculation, repeat the experimental procedure with more care to correct the mistake.

Calculating Percent Error and Percent Difference of Measurements and Experimental Results

(adapted from http://www.studyphysics.ca/newnotes/20/unit01_kinematicsdynamics/chp02_intro/lesson05.htm)

There are three common ways to calculate your error:

- absolute error
- percentage error
- percentage difference

Absolute Error is when you subtract the accepted value from your measured value.

Absolute Error = Measured Value minus Accepted Value

- A positive answer means your measured value is larger than the accepted value
- A negative answer means your measured value is smaller than the accepted value

Percent Error is the most common way of representing the degree to which your measured value differs from the generally accepted value.

Equation:

Percent Error = (Absolute Error / Accepted Value) × 100%

= (Measured Value - Accepted Value / Accepted Value) × 100%

For example, if your experimental results determine that the acceleration due to gravity is 9.70m/s^2, whereas the accepted value is 9.80m/s^2, the percentage error is:

Percent Error = [(9.70m/s^2 - 9.80m/s^2) / (9.80m/s^2)]/100% = -1.00%

Which means you got a -1.00% error. *The negative sign means that your experimental measured value is less than the accepted value.*

Percent Difference is useful if you have two measurements of the same thing and want to determine how close they are to being equal to each other.

Equation:

Percent Difference
=[(absolute value of the difference in measurements)/(average of measurements)]×100%

Don't confuse this with percentage error. Here we have two measurements you've made, but no "accepted value." For example, you measure the length of a desk twice and get the numbers 1.15m and 1.13m.

Percentage Difference = [(1.15m - 1.13m) / [(1.15m +1.13m)/2]×100% = 1.75%

The two measurements differ by 1.75%

Percent difference is always expressed as a positive number (absolute value).

Introduction to Errors and Error Analysis

Summarized/adapted from:
http://www.physics.ryerson.ca/sites/default/files/u3/2011/04/Labs-IntroToErrorsFinal.pdf

Many students imagine that an "error" is something they have done wrong. However, in science, the word "error" means the "uncertainty" which accompanies every measurement. We can do our best to minimize the errors and uncertainties, but we cannot fix or avoid measurement "uncertainties", no matter how careful we are.

For example, a meter stick only measures to the nearest millimeter. Therefore, when using a meter stick it is not possible to make a measurement that is more precise than "to the nearest 1mm". You may be able to estimate a value between the markings (e.g. to the nearest 0.5 mm), but at best that is a rough estimate. If you need to make a more precise measurement of distance (for example, to measure the thickness of a strand of hair), a meter stick is not the best measuring device to use. You would have to use a more precise measuring device, such as a micrometer.

In high school physics you are expected to be able to correctly identify and describe sources of experimental error (uncertainty). If you continue to take science courses in College or University you will learn to mathematically analyze inherent experimental errors.

Errors associated with *Precision* vs *Accuracy*

There are two main types or categories of error associated with measurements, although distinguishing the two types can be a challenge. The categories of error are errors in ***precision*** and ***accuracy***.

Precision

Precision is usually related to random error distribution associated with a particular experiment or even with a particular type of experiment. For our purposes at the high school level, you can think of precision in relation to the number of decimal places of the measurement. For example, a measurement of 10.345 m is more *precise* than a measurement of 10.3 m. Both values round to 10.3 m, but 10.345 m has a larger number of decimal places.

Accuracy

Accuracy is related to the existence of systematic errors, for example, the incorrect calibration. It relates to the extent to which a measured value represents the true value. For example, if you forget to "zero" an electronic balance, your measurement will be inaccurate. If the scale reading is 3.5 g when the scale is empty, and then you place a 25.0 g rock on the scale, the new scale reading will be 28.5g. If you didn't realize that you forgot to "zero" the scale before taking the measurement, you would think mistakenly that the mass of the rock is 28.5 g.

Major Sources of Error

Reading Error

Almost all direct measurements involve reading a scale (ruler, caliper, stopwatch, analog voltmeter, etc.) or a digital display (e.g. digital multimeter or digital clock). Sources of uncertainty depend on the equipment we use. One of the unavoidable sources of errors is a reading error. Reading Error refers to the uncertainties caused by the limitations of our measuring equipment and/or our own limitations at the time of measurement (for example, our reaction time while starting or stopping a stopwatch). This does not refer to any mistakes you may make while taking the measurements. Rather it refers to the uncertainty inherent to the instrument and your own ability to minimize this uncertainty.

A reading error affects the precision of the experiment. The uncertainty associated with the reading of the scale and the need to interpolate between scale markings is relatively easy to estimate. For example, consider the millimeter (mm) markings on a ruler scale. For a person with a normal vision it is reasonable to say that the length could be read to the nearest millimeter at best. Therefore, a reasonable estimate of the uncertainty in this case would be $\Delta l = \pm\ 0.5$ mm which is half of the smallest division. A general rule for evaluating the reading error is to use half of the smallest division (in case of a meter stick with millimeter divisions it is 0.5 mm), but this does depend on individual circumstances. In practice, only the observer/experimenter can ultimately estimate his/her limitation in error evaluation. For example, for a person with a poor vision the uncertainty while using the same ruler might be greater than one millimeter. If the scale markings are further apart (for example, meter stick with markings 1 cm apart), one might reasonably decide that the length could be read to one-fifth or one-fourth of the smallest division.

For many digital instruments, you may assume that the reading error is ± 1/2 of the last digit displayed; e.g. if the reading of the digital timer in the free fall experiment is 682.6 ms, the error can be assumed to be ± 0.05 ms, and you could quote the measurement as (682.60 ± 0.05) ms.

Random Error

Random Error refers to the spread in the values of a physical quantity from one measurement of the quantity to the next, caused by random fluctuations in the measured value. For example, in repeating measurements of the time taken for a ball to fall through a given height, the varying initial conditions, random fluctuations in air motion, the variation of your reaction time in starting and stopping a watch, etc., will lead to a significant spread in the times obtained. This type of error also affects the precision of the experiment. Sometimes the measured value is higher than expected, and sometimes it is lower. In this case, it is wise to measure the same thing multiple times (trials), and then calculate the average.

Physical Design Challenges

There are other sources of uncertainty in direct measurements that can be much more important than uncertainties in the scale or display readings. For example, in measuring the distance between two points, the main problem may be to decide where those two points really are. For example, in an optics experiment it is often necessary to measure the distance between the center of the lens and the position of the focused image. But even a thin lens is usually several millimeters thick, which makes locating the center a difficult task. In addition, the image itself may appear to be focused in a region that spans a range of several millimeters. Parallax is another significant source of a reading error, where the reading depends on your line of sight.