**TYPES OF ERRORS**

Measurement errors may be classified as either **random** or **systematic**, depending on how the measurement was obtained (an instrument could cause a random error in one situation and a systematic error in another).

**Random errors** are statistical fluctuations (in either direction) in the measured data due to the precision limitations of the measurement device. Random errors can be evaluated through statistical analysis and can be reduced by averaging over a large number of observations (see standard error).

**Systematic errors** are reproducible inaccuracies that are consistently in the same direction. These errors are difficult to detect and cannot be analyzed statistically. If a systematic error is identified when calibrating against a standard, applying a correction or correction factor to compensate for the effect can reduce the bias. Unlike random errors, systematic errors cannot be detected or reduced by increasing the number of observations.

When making careful measurements, our goal is to reduce as many sources of error as possible and to keep track of those errors that we cannot eliminate. It is useful to know the types of errors that may occur, so that we may recognize them when they arise. Common sources of error in physics laboratory experiments:

**Incomplete definition** (may be systematic or random)

One reason that it is impossible to make exact measurements is that the measurement is not always clearly defined. For example, if two different people measure the length of the same string, they would probably get different results because each person may stretch the string with a different tension. The best way to minimize definition errors is to carefully consider and specify the conditions that could affect the measurement.

**Failure to account for a factor** (usually systematic)

 The most challenging part of designing an experiment is trying to control or account for all possible factors except the one independent variable that is being analyzed. For instance, you may inadvertently ignore air resistance when measuring free-fall acceleration, or you may fail to account for the effect of the Earth's magnetic field when measuring the field near a small magnet. The best way to account for these sources of error is to brainstorm with your peers about all the factors that could possibly affect your result. This brainstorm should be done **before** beginning the experiment in order to plan and account for the confounding factors before taking data. Sometimes a **correction** can be applied to a result **after** taking data to account for an error that was not detected earlier. **Environmental factors** (systematic or random)

Be aware of errors introduced by your immediate working environment. You may need to take account for or protect your experiment from vibrations, drafts, changes in temperature, and electronic noise or other effects from nearby apparatus.

**Instrument resolution** (random)

 All instruments have finite precision that limits the ability to resolve small measurement differences. For instance, a meter stick cannot be used to distinguish distances to a precision much better than about half of its smallest scale division (0.5 mm in this case). One of the best ways to obtain more precise measurements is to use a **null difference** method instead of measuring a quantity directly. **Null** or **balance** methods involve using instrumentation to measure the difference between two similar quantities, one of which is known very accurately and is adjustable. The adjustable reference quantity is varied until the difference is reduced to zero. The two quantities are then balanced and the magnitude of the unknown quantity can be found by comparison with a measurement standard. With this method, problems of source instability are eliminated, and the measuring instrument can be very sensitive and does not even need a scale.

**Calibration** (systematic)

 whenever possible, the calibration of an instrument should be checked before taking data. If a calibration standard is not available, the accuracy of the instrument should be checked by comparing with another instrument that is at least as precise, or by consulting the technical data provided by the manufacturer. Calibration errors are usually linear (measured as a fraction of the full scale reading), so that larger values result in greater absolute errors.

**Zero offset** (systematic)

When making a measurement with a micrometer caliper, electronic balance, or electrical meter, always check the zero reading first. Re-zero the instrument if possible, or at least measure and record the zero offset so that readings can be corrected later. It is also a good idea to check the zero reading throughout the experiment. Failure to zero a device will result in a constant error that is more significant for smaller measured values than for larger ones.

**Physical variations** (random)

It is always wise to obtain multiple measurements over the widest range possible. Doing so often reveals variations that might otherwise go undetected. These variations may call for closer examination, or they may be combined to find an average value.

**Parallax** (systematic or random)

This error can occur whenever there is some distance between the measuring scale and the indicator used to obtain a measurement. If the observer's eye is not squarely aligned with the pointer and scale, the reading may be too high or low (some analog meters have mirrors to help with this alignment).**Instrument drift** (systematic) — Most electronic instruments have readings that drift over time. The amount of drift is generally not a concern, but occasionally this source of error can be significant.

.**Personal errors**

 come from carelessness, poor technique, or bias on the part of the experimenter. The experimenter may measure incorrectly, or may use poor technique in taking a measurement, or may introduce a bias into measurements by expecting (and inadvertently forcing) the results to agree with the expected outcome.

Gross personal errors, sometimes called **mistakes** or **blunders**, should be avoided and corrected if discovered. As a rule, personal errors are excluded from the error analysis discussion because it is generally assumed that the experimental result was obtained by following correct procedures. **The term human error should also be avoided in error analysis discussions because it is too general to be useful**.