Formal Laboratory Report and Analysis Methods

Scientists have developed a set of conventions to make the results of their work easily accessible to their peers; by following the same conventions for your lab reports, you allow others to analyze your work. The following outlines briefly how to apply their conventions to your formal laboratory reports in science.

0. **Top of Page 1 or Front Cover:**

Depending on your instructor's preference, he/she may or may not require a cover page. The following information should be found either on your cover page or at the top of your first page.

Experiment Title
Your Name (first and last)
Your Partner's Name(s)
Date of Submission

Structure of Lab Reports

Reports will be divided generally into the following sections, in order of appearance:

1. **Introduction:** Briefly outline the concepts and/or theories that are to be tested or investigated in this particular experiment (1-2 paragraphs are usually sufficient). Introductions will combine the ideas of a stated problem and a summary explanation of what the results should show or have shown. This section tells the reader why you did the experiment, i.e., the purpose of the study. It also contains background information that introduces the concepts that you will analyze and discuss as well as the methods that you will use to analyze them. In some reports this section may be broken down into Problem and Hypothesis sub sections where you are asked to make predictions in advance of performing the experiment, but in general a formal university-bound report should have an introduction. Often a hypothesis is not included where a statement defining the problem has been made, this depends on the instructor's preference. When the reader finishes reading the introduction, he or she should know what to expect in the report. Some instructors may even ask you to write an introduction after the experiment is completed so that you can include the results in your introduction section.

2. **Materials:** You will provide a list of the materials that you used. You must actually list your materials. Materials should be listed in the order used. The volume and error of all chemical volumes or chemical concentrations that were used must be specified in your materials (ex. 100mL ± 1mL). Some instructors may allow you to reference a secondary source for your materials and procedure.

3. **Apparatus Diagram/Equipment Diagram:** In this section a diagram of your apparatus setup will be included. Diagrams should be labeled, titled and indexed as a figure number (ex. Figure 1: Experimental Apparatus). The title should be under the diagram, the labels should be placed to the left of the diagram and the labels should be vertically aligned.

4. **Procedure:** This section describes what you did in enough detail that someone else could repeat the experiment. You may refer to the text under this heading. However, if any changes were made to the procedure or materials list, then you must describe the changes. Your description must therefore be quantitative and specific (for instance, what temperature was the mixture heated to and for how long?). The procedure should be written in the third person and in past tense (i.e., "The solution was heated.").

5. **Observations:**

a) In this section you will record your qualitative and quantitative raw data as a part of your report's body. Tables, labeled diagrams or other raw data recording methods may be used here. All tables require descriptive titles as well as appropriate headings with measurement units and must include uncertainty values. No interpretation of data or calculations should be included in your observations, and certainly no inferences.
b) Always record your observations in INK! Do not use liquid paper, pencil, or scratch out any errors. Simply cross out errors with a straight line, then write the correct value. (Some instructors may choose to initial your original observations to ensure that they are not altered.)
c) Your original observations recorded in the lab must be included with your report as a stapled attachment. Making a good copy is not allowed.
d) Observations may include formal scientific diagrams if appropriate. These should be completed during class time.

6. **Calculation and Analysis of Results:**

In this section, you interpret the data that was presented in your observations and complete the required calculations from your experiment.

a) Calculations should be done after all data has been collected. Show all formulas and values being used as well as units and appropriate interpretation of significant digits. If the same calculation is done multiple times you only need to show one sample calculation.
b) Calculation Summary Tables are useful for recording multiple calculation results. Both tables of values and figures (graphs) should be numbered sequentially, and each should have a descriptive title (ex. Table 3: Acceleration of Motion Cart, or Graph 2: pH vs Time).
c) Whether requested or not, every graph or figure should have a brief interpretation of its meaning placed below it. A graph without interpretation means very little to the casual reader.
d) If you include supporting graphs, data tables, sample calculations, drawings or diagrams on blank paper at the end of the report. These figures must be referred to in this section and indexed with an appendix number.
e) Items in the back of your report are called Appendix items (or appendices). Each appendix items must be numbered sequentially and titled (ex. Appendix 6: % Error of a_g Measurement According to Method 2). Each value stated or graph referred to in the body of your analysis must be referenced with an Appendix number so that the calculations or data source can be located (ex. *"The % error for the acceleration was found to be 37.6%, which is not in acceptable agreement with the theoretical results (Appendix 6)."*).

7. **<u>Discussion:</u>** This is the most important part of your report. In this section, you explain to the reader the significance of the results you presented above (i.e., what they mean). Any direct questions asked of you should be answered in a separate section titled "**<u>Discussion Questions</u>**". Your ideas must flow in a logical form and make reference to your observations and calculated results. You must support every claim that you make with evidence!

8. **<u>Conclusion and Evaluation:</u>** Briefly summarize the most important aspects of the lab and what was proven or shown. Make sure to include any final values or trends as well as percent errors or percent differences. Compare any appropriate values to values that would be expected according to theory or literature. Your conclusion must relate your results back to the original purpose, hypothesis, or problem that this experiment is addressing. (ex. *"Since it was observed that _______ it can therefore be concluded that ________."*). Your conclusion should finish with a statement or statements about how your results can be applied in human society or a comment about the implications of your results for further scientific inquiry.

   <u>Error Discussion:</u>

   a) A comparison of your results to literature, background information from the Introduction, or theoretical results.
   b) An evaluation of the reliability of your results, discussing any sources of error (procedural, NOT human error) and attempting to explain any results that do not make sense.
   c) Suggestions for how to overcome introduced error in an attempt to make a future attempt of this lab more accurate and therefore more reliable.

<u>Consider the following points as you write your lab:</u>

a) Passive vs. Active voice: Scientists often use passive voice, particularly when describing experimental protocols. For example, "The solution was heated at 100°C for 5 hours," rather than, "I heated the solution at 100°C for 5 hours." Please report your actions in the passive voice.

b) Past vs. Present tense: Actions that took place in the past are rightly described in the past tense. Results are assumed to reside in the present and are described in the present tense. For example, "The solution was heated at 100°C for 5 hours," because that action was carried out at a specific past time. However, if you took an infrared spectrum of the sample you made, to describe the spectrum, you would use the present tense: "The absence of outliers in the velocity time graph confirms that the friction coefficient is constant along the ramp."

c) Never start a sentence with a numeral ("2" is a numeral; "Two" is not). When reporting a quantitative amount at the start of a sentence, use the following format: "Salicylic acid (1.00 g) was added to. . . ." It is incorrect to write, "1.00 g salicylic acid was added. . .," and it is imprecise to write "One gram salicylic acid was added. . . ."

d) "Data" is a plural word; the singular form (for one point) is "datum." Saying, "The data shows that. . ." is like saying, "The people says that. . . ."

Referencing

A) Appendix:

All external sources must be referenced at the end of the lab report. If you write a sentence that does not contain a reference, then it is assumed that the idea was your own. Never copy statements from your partner's lab report or an external source. Plagiarism in any form is considered to be dishonest behaviour, and will receive serious consequences.

B) Print Resources:

Secondary sources will be referenced according to current APA standards as outlined in the school style guide. An up to date version of this referencing format can also be found online, as APA is a worldwide referencing standard in science.

ERROR ANALYSIS

The verification of a physical law or the determination of a physical quantity involves measurements. Any uncertainty in these measurements will result in an uncertainty in the final result. These uncertainties are called experimental errors.

Part1:

Error Types

Errors resulting from measurements are usually grouped into two classes: **systematic errors** and **random errors**.

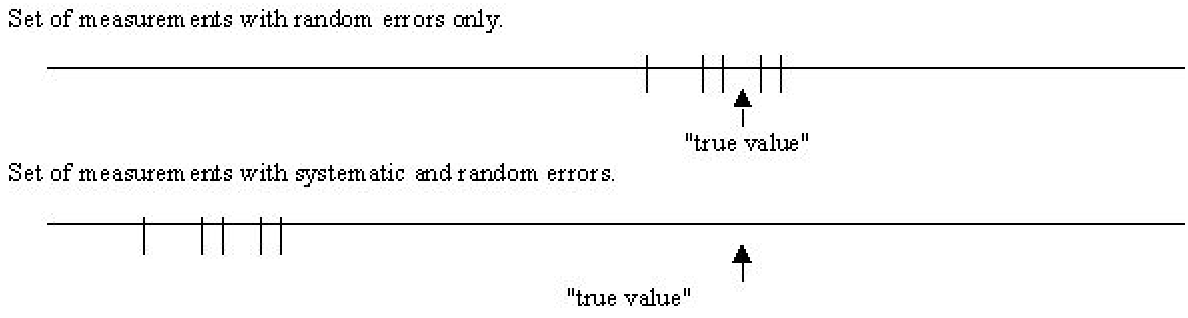
A) Systematic errors are due to identifiable causes and can, in principle, be eliminated. Errors of this type result in measured values that are consistently too high or consistently too low. Systematic errors may be of four kinds:

1. *Instrumental:* A poorly calibrated instrument such as a thermometer that reads 102 °C when immersed in boiling water and 2 °C when immersed in ice water at atmospheric pressure.
2. *Observational:* For example, parallax in reading a meter scale.
3. *Environmental:* For example, and electrical power "brown out" that causes measured currents to be consistently too low.
4. *Theoretical:* Due to simplifications or approximations in the model or equations that describe the system such as neglecting frictional forces.

Experimentalists want to identify and eliminate systematic errors.

B) Random errors are ones that cause about one-half of the measurements to be too high and one-half to be too low. Sources of random errors cannot always be identified. Thus, taking repeated measurements and averaging the results is a good way to reduce random errors. Random errors can be quantified and their effects on the quantity or physical law under investigation can often be determined.

The distinction between random errors and systematic errors can be illustrated with the following example. Suppose the measurement of a physical quantity is repeated five times under the same conditions. If there are only random errors, then the five measurements will be spread about the "true value"; some will be too high and others will be too low. If in addition to the random errors there is also a systematic error, then the five measurements will be spread not about the true value, but about some other value. See diagram below.



Part 2:
Estimation and Error Range Methods (Uncertainty)

When measuring a physical quantity using a calibrated instrument, the measurement of any value smaller than the smallest division on the measuring instruments is an estimate.

Uncertainty is defined as the expected error interval or range of the measurement of any quantity expressed in the same units as the measurement. The job of the experimentalist is to assign some limits within which they believe the reading to be accurate.

A) Instrumental Uncertainty:
Good experimental practice suggests that the uncertainty be described **as plus and minus half of the smallest unit of measure on the measuring instrument**. For example, If a reading of 10.2 cm was taken on a metre stick calibrated in mm then the uncertainty would be ± 0.05 cm. The quantity would be reported as 10.2 ± 0.05 cm. All measurements with this same metre stick would have the same uncertainty.

B) Percent Uncertainty:
The percent uncertainty can be found by dividing the instrumental uncertainty by the measured value. % uncertainty = (0.05/10.2)x100% = 0.49%. So the instrumental uncertainty can be expressed as a % uncertainty 10.2cm ± 0.49%.

C) Statistical Uncertainty:
If it is possible and practical to repeat measurements several times, then treat random errors in the following manner. Repeat the measurement n times. Calculate the mean value of the measurements. Then calculate the **average deviation from the mean**, and finally the **uncertainty in the mean**. See the example below.

Example: Measuring the diameter of a cylinder

Trial	Diameter (cm)	Deviation from the mean
1	5.28	0.00
2	5.22	0.06
3	5.28	0.00
4	5.32	0.04
5	5.32	0.04
6	5.24	0.04
7	5.24	0.04
8	5.26	0.02
9	5.30	0.02
10	5.34	0.06
Total	52.80	0.32
Mean	**5.28**	

$$\text{Average deviation from the mean} = \frac{\text{Sum of deviations}}{\text{Number of trials (n)}} = \frac{0.32}{10} = 0.032 \text{ cm or } 0.03 \text{ cm}$$

$$\text{Uncertainty in the mean} = \pm \frac{\text{Average deviation from the mean}}{\sqrt{n}} = \pm \frac{0.032 \text{ cm}}{\sqrt{10}} = \pm\ 0.01 \text{ cm}$$

Therefore the diameter of the cylinder would be reported as 5.28 ± 0.01 cm.

Part 3:
Graphs and Analysis With Error Considerations Included

A graph is often the most concise and meaningful way to display data. It is important to show experimental errors on graphs. An experimental measurement is not exact and should be represented by a small range of possible values called an error interval. It is essential that every set of measurements be shown with an error interval. These errors can be shown on a graph using error bars (see the diagram below).

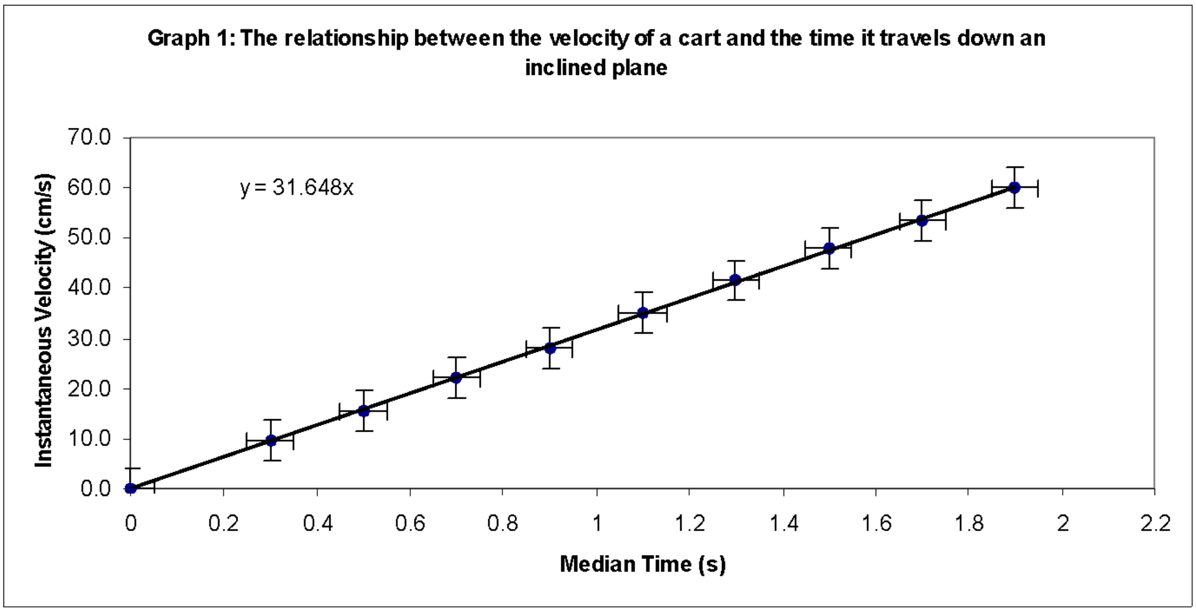
Once the points have been plotted and the error bars drawn in, it is important to draw the line or curve of best fit through the data points. To draw the line or curve of best fit, draw a smooth curve or line which comes closest to most of the points and approximately lies within the error bars of all points. If a straight line can be fitted to the points so that it falls within the error bars of all points, then within the limits of the experiment the relationship between the two variables is linear.

Once the line of best fit has been drawn in, it is usually important to calculate its slope. The slope of the line of best fit can be calculated by using **two new points on the line**. DO NOT USE THE EXPERIMENTAL DATA POINTS. PICK TWO NEW POINTS ON THE LINE. If (x_1, y_1) and (x_2, y_2) are two new points on the line then the slope is given by

$$m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{rise}{run}$$

Since the variables you plot will be physical quantities with units, the rise, run and slope should be given units. To determine the units of the slope use

$$units\ of\ the\ slope = \frac{units\ of\ the\ rise}{units\ of\ the\ run}.$$



The **<u>Error Bars</u> on the above graph indicate the ± error values associated with each plotted point. Ex. ***(0.3 ± 0.05seconds, 10 ± 5 cm/s)***

<u>Significant Digits</u>

The certainty of any measurement is communicated by the number of significant digits in the measurement. In a measured or calculated value, significant digits are the digits that are certain plus one estimated (uncertain digit). Significant digits include all digits correctly reported from a measurement.

<u>Part 1:</u>
There are **rules** to determine how many significant digits there are in any value.

1. All non-zero digits are significant. For example, 5.37 has three significant digits

2. Zeros between non-zero digits are significant. For example, 30.15 has four significant digits

3. In a measurement with a decimal point, zeros placed before other digits (leading zeros) are not significant. For example 0.002 has one significant digit.

4. Zeros places after other digits behind a <u>decimal</u> are significant. 9.100 and 802.0 each has four significant digits

5. Zeros are ambiguous in large numbers that do not contain a decimal point. These zeros are not significant. For example 45 000 000 has 2 significant digits. Scientific notation is usually used to indicate if the zeros at the end of a measurement are significant. 4.50×10^7 has 3 significant digits and 4.500×10^7 has 4 significant digits.

6. There is a class of numbers to which the rules of significant digits do not apply. These are exact numbers such as counted or defined values (like conversion factors). Examples of exact numbers are 30 students or 60 s/min.

Part 2:
Significant Figures in Calculations

The underlying rule when you are doing calculations is a calculated or derived value cannot be more precise than the measurements that were actually made. To determine the number of significant digits in your answer, you need to know the rules applying to significant figures in calculations.

Multiplying and Dividing
When multiplying and/or dividing, the answer must have the same number of significant digits as the measurement with the fewest number of significant digits.

Adding and Subtracting
When adding and subtracting measured values, the answer must have the same number of decimal places as the measured value with the fewest decimal places.

Rounding Off
The following rules should be used when rounding calculated answers.

1. When the first digit discarded is less than five, the last digit retained should not be changed.
   3.141 326 rounded to 4 digits is 3.141

2. When the first digit discarded is greater than five, or if it is a five followed by at lest one number other than zero, the last digit retained is increased by 1 unit.
   2.221 672 rounded to 4 digits is 2.222
   4.168 523 rounded to 4 digits is 4.169

3. When the first digit discarded is a five followed by only zeros, the last digit retained in increased by 1 if it is odd but not changed if it is even.
   2.35 rounded to 2 digits is 2.4
   2.45 rounded to 2 digits is 2.4
   -6.35 rounded to 2 digits is -6.4