Memorial University of Newfoundland

Department of Physics
and Physical Oceanography

Physics 1050

Laboratory Workbook

Fall 2018
Winter 2019

_____

Laboratory Computers

Logging in:

Your user name is written at the top of your monitor: e.g *maclab32* or *maclab46.* Your password is *raptors*.

We take attendance for every lab. To do so, double click

Lab-Attendance

Select your course and lab number.

Enter your name and student number.

Both partners need to complete the sign in procedure. You will sign out on paper as you leave the lab.

Accessing lab files:

On desktop screen after login, lab files are organized by course number.	 P1050
Each lab organized by lab number. Inside this folder all the files required including the instructions file and for collecting and analysing data.	 Lab 1
The instruction files are in .pdf format. Use the instruction files from the lab folder as these contain links to open necessary applications.	

_____

Laboratory Guidelines

1.) All Physics 1050 students are required to complete **six** experiments. You must obtain a minimum mark of 50% in the laboratory in order to pass the course.

2.) Laboratory classes will be *one hour fifty minutes long*. Please consult the schedule posted outside the lab or the MUN Physics website for the exact dates.

3.) Be prepared and on time. *Prelabs* are to be completed and checked at the door for each experiment. You may not start the laboratory experiment if you are more than *15 minutes late* for any reason.

4.) Prelab questions are to be done prior to beginning the laboratory and are checked by staff at the door. The prelab questions are found on the Memorial University physics website at:
http://www.mun.ca/physics/undergraduates/fylabs/p1050

5.) Laboratory reports will be completed in the lab and are submitted at the end of the lab period.

6.) Experiments are performed with partners. While partners are expected to share data and discuss the experiment, each person independently writes his own report. **Plagiarism is strictly prohibited**.

7.) Keep your work area tidy and return apparatus to the condition in which you found it. Coats and bags should be placed under the benches or away from areas where people are working. Eating and drinking are **not permitted** in the laboratory.

8.) If you are absent from the laboratory due to illness, you should contact your instructor within 48 hours. If you know you will be absent for some other reason, you should inform the laboratory instructor beforehand, to see if alternate arrangements may be made.

9.) Laboratory equipment must be handled with care at all times. All breakages and accidents must be reported to the instructor immediately and equipment should be tidied and put away after each experiment.

10.) A first aid kit is available.

_____

Introductory Comments

The Physics 1050 and Physics 1051 laboratories will introduce you to concepts and techniques to help aid in your understanding of important course topics and that you will encounter again in other courses. More importantly, we hope that your experience will give you an appreciation of the study of these physical phenomena. In many cases, the use of digital sensors and analysis will substantially simplify and accelerate the process of data collection. However, along with the ability to rapidly accumulate large quantities of data comes the growing need for meaningful interpretation of such data. You will be expected to make effective use of your laboratory time for analysis and interpretation of your observations.

The experiments in this course have been designed to illustrate important physical principles and to give you experience with electronic data collection and analysis. In order to gain the most benefit from the lab, it is essential that you make an effort to understand both the physical principles underlying the phenomena and the measurement.

This manual is divided into two parts: The first part contains a reference section of material that will be required throughout your semester in the Physics lab. The second part is your Workbook, where you will write and record your interpretation of your results from these experiments. As you perform and analyse each experiment, you will record your observations in these sheets and submit them for grading. You will be responsible for understanding the principles of the phenomena you investigate in the laboratory and the methods by which you carry out the investigation.

One important role of these experiments, is to introduce you to the concept of error analysis in a laboratory environment. We use basic principles of uncertainty estimation to track error propagation in measurements. It's an important factor in understanding what it means for values to be in agreement with one another; this is one method of how we use data to confirm a relationship between expected and measured quantities. The upcoming sections aim to illustrate how we track uncertainties in the lab and how we yield information from a graph.

It is very important that you follow the graphic alerts shown in the following table as they ensure that you do not miss a key instruction, question, or table and that you adhere to safety or equipment handling warnings.

_____

The following graphics are found throughout the laboratory instructions and should be noted for their importance.

!	A note or a warning. DO NOT IGNORE THESE!
Q	A question that must be answered in the Laboratory Workbook
LW	Data or other information must be entered in the Laboratory Workbook
P	Indicates when an item must be printed
CP	Checkpoint! You require instructor's initials in your Laboratory Workbook before proceeding
	A clickable icon that opens Logger Pro
GA	A clickable icon that opens Graphical Analysis

_____

Error Analysis

These pages contain some of the basic formulae you will use in order to perform the necessary error analysis in your calculations.

Experimental results always have uncertainties associated with them. It is important to track these uncertainties according to the rules discussed in this manual. Uncertainties arise not from making mistakes in calculations, but from inherent limits in making a measurement.

Significant Figures

Non-zero digits are always significant and zeros are significant when between other digits (e.g 4009 has 4 significant digits) or after a decimal point (e.g. 54.03 has 4 significant figures as does 82.00×10^3). Whole numbers are considered to have infinite significant digits. (e.g. if a hair dryer uses 1.2 kW of power, then 2 identical hairdryers use 2.4 kW (2 significant figures)).

We typically write in scientific notation to avoid ambiguity with zeros. For example, in 80,400 the significant digits are unknown as the last two zeros may or may not be significant. Instead, we write 8.04×10^4 indicating there are 3 significant digits.

Experimental Error and Uncertainty

The difference between a measured or calculated value and the corresponding true value is called the **experimental error** (or **error**). Since we usually don't know the true value of the quantity in question, the values of the experimental errors must be estimated and some judgment is involved in making realistic estimates. An estimate of the experimental error in a quantity is called the **uncertainty**.

Types of Uncertainties

Experimental errors arise from a variety of sources and may be broadly classified as **random errors** and **systematic errors**.

Random errors are those errors that affect the results in a random way, and are equally **likely** to give values that are too high or too low. As an example, suppose we wish to determine the time for one cycle of a pendulum using a stopwatch. The difficulty of starting and stopping the watch at exactly the correct time ("reaction time error") means that repeated measurements of this time will differ slightly from each other. This is an

_____

example of a random error. Random error can be reduced by taking the average or mean of a set of measurements.

Systematic errors are those that tend to affect the experimental results in a consistent way, so **all** the values are either too high or too low. In the stopwatch example above, if the watch was running slow, all the values would be too low by the same amount, and the effect of this systematic error could not be reduced by taking the average of a set of repeated measurements.

Absolute and Relative Uncertainty

δx represents the **absolute** error or uncertainty in a measured quantity. This absolute uncertainty is the acceptable or expected variance in some measured value. We also have the **relative uncertainty**, which is determined by dividing the absolute uncertainty by the value of the quantity itself, namely $\delta x / x$.

The uncertainty, in the scope of this course, is always rounded to 1 significant figure.

Values with a lower absolute uncertainty have a higher precision. We can also compare the precision of multiple values, even of different units, using our values and their uncertainties. By calculating the relative uncertainty, we yield a unitless quantity whereby, again, the lower relative uncertainty indicates the greater level of precision.

Range

A result is generally reported in the form $x \pm \delta x$, where we have the measured value x with acceptable amount of absolute uncertainty δx. It is generally good practice to keep both the value and its uncertainty in the same units.

The "true" value of the result being measured is unknown, but will likely lie in the range of $x - \delta x$ to $x + \delta x$. So, when comparing two or more measurements of the same quantity, it is generally expected to show that their ranges overlap with each other.

Comparing answers and range:

When comparing two numbers to see if they agree, write the ranges of both numbers and see if they overlap.

_____

Example:
Given two values of acceleration due to gravity: $g_1 = 9.76 \pm 0.03 m/s^2$ and $g_2 = 9.80 \pm 0.02 m/s^2$. Do these values agree?

1. Write the range of g_1: $9.73 \: to \: 9.79 \: m/s^2$.
2. Write the range of g_2: $9.78 \: to \: 9.82 m/s^2$.
3. If the ranges overlap, the values agree. If the ranges do not overlap, the values do not agree. In this case, the ranges do overlap and therefore they agree.

Combining Errors in Laboratory Results

Two or more measured quantities are often combined to determine a new quantity. When doing so, the experimental uncertainty of the new quantity must be determined using the following rules.

Adding and Subtracting Quantities:
When adding or subtracting measured quantities, the absolute uncertainty in the result is the sum of the absolute uncertainties in the measured quantities.

$$\text{If } z = x + y \text{ or } z = x - y,$$

$$\text{then } \delta z = \delta x + \delta y.$$

Example:
$$A = (122 \pm 5) \: m, \qquad B = (207 \pm 2) \: m$$

$$C = A + B = 122 \: m + 207 \: m = 329 \: m$$

$$\delta C = \delta A + \delta B = 5 \: m + 2 \: m = 7 \: m$$

$$C = (329 \pm 7) \: m$$

Multiplying and Dividing Quantities:
When multiplying or dividing measured quantities, the relative uncertainty in the result is the sum of the relative uncertainties in the measured quantities.

$$\text{If } z = \frac{x}{y} \text{ or } z = xy,$$

$$\text{Then } \frac{\delta z}{z} = \frac{\delta x}{x} + \frac{\delta y}{y}.$$

Example:

_____

$$A = (120 \pm 5)m, \quad B = (200 \pm 10)m$$

$$C = A \times B = 120\ m \times 200\ m = 24000\ m^2$$

$$\frac{\delta C}{C} = \frac{\delta A}{A} + \frac{\delta B}{B} = \frac{5\ m}{120\ m} + \frac{10\ m}{200\ m} = 0.0917$$

$$\delta C = \frac{\delta C}{C} \times C = 0.0917 \times 24000\ m^2 = 2200\ m^2$$

$$C = (24000 \pm 2000)m^2 \quad or \quad (2.4 \pm 0.2) \times 10^4 m^2$$

Note: The uncertainty $\delta C = 2200\ \text{m}^2$ has been rounded to one significant figure, so it becomes $2000\ \text{m}^2$.

Multiplication by a constant:
When multiplying by a constant, the uncertainty is multiplied by the same constant. This rule is a simplification of the multiplication-division rule noted above.

If $z = Ax$, where A is a constant,

then $\delta z = A\delta x$.

Quantities with exponents:
Considering cases where a quantity has an exponent in its expression, this rule can be useful in determining how the uncertainty can be determined. This rule also follows from the multiplication-division rule.

If $z = x^n$,

then $\dfrac{\delta z}{z} = n\dfrac{\delta x}{x}$.

_____

Combination of rules:
When the desired result depends on more than two quantities, the uncertainty may be calculated by breaking down the algebraic expression term by term. Thus if $a = bc^2/d$, the absolute uncertainty in a is given by:

$$\frac{\delta a}{a} = \frac{\delta b}{b} + 2\frac{\delta c}{c} + \frac{\delta d}{d},$$

$$\delta a = a\left(\frac{\delta b}{b} + 2\frac{\delta c}{c} + \frac{\delta d}{d}\right),$$

Multiple Measurements:
To reduce the effects of random error, we often take N measurements of the same quantity, where N denotes the number of measurements taken. Taking the average or mean, denoted $\bar{x}$, obtains the best estimate of the "true value". We take an average by

$$\bar{x} = \frac{\Sigma x_i}{N}.$$

To estimate the uncertainty in an average, we apply statistical analysis. If we consider, when you take an average of a set of measurements, some measurements will be greater than the average, some less than the average. The standard deviation of a set of values, denoted σ_x, is a measure indicating how much spread there is in a data set. It is found by the expression:

$$\sigma_x = \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{N - 1}}$$

This calculation is generally easily determined with computer software as a 'built-in' function. It is generally not taken as an uncertainty estimate however.

We most commonly report standard error $\sigma_{\bar{x}}$ as the **uncertainty associated with the average**. Standard error is calculated as:

$$\sigma_{\bar{x}} = \delta\bar{x} = \frac{\sigma_x}{\sqrt{N}} \quad ,$$

where σ_x is the standard deviation of our measurements x, and N is the number of measurements taken.

Generally speaking, software will calculate the average and standard deviation and you will have to compute the standard error and take that to be the uncertainty of the average.

_____

<u>Sample calculation with multiple measurements:</u>
In the following tables, calculations are shown for illustrative purposes only. In your Workbook, you are not required to show workings in your tables. Assume we have taken a set of $N = 8$ measurements of length and have calculated the mean:

$L\ (m)$
21.23
20.98
21.05
20.86
20.78
20.91
20.09
21.62

To draw meaning from these values, we must employ a bit of statistics. The process to do so, would follow these steps:

1. Calculate the **average** of our measurements.
2. Determine the **standard deviation**. Typically, our software will calculate this from our data.
3. Calculate the **standard error**. This is taken as our uncertainty in an average.
4. Write our value in $\bar{L} \pm \delta\bar{L}$ form.

From the values of L noted above, the entire process (including the details of the calculation of standard deviation are in the following table.

$L\ (m)$	$L_i - \bar{L}\ (m)$	$(L_i - \bar{L})^2\ (m^2)$
21.23	$21.23 - 20.94 = -0.29$	0.084
20.98	$20.98 - 20.94 = 0.04$	0.0016
21.05	$21.05 - 20.94 = 0.11$	0.012
20.86	$20.86 - 20.94 =- 0.08$	0.0064
20.78	$20.78 - 20.94 = -0.16$	0.026
20.91	$20.91 - 20.94 = -0.03$	0.00090
20.09	$20.09 - 20.94 = -0.85$	0.72
21.62	$21.62 - 20.94 = -0.68$	0.46
$\bar{L} = \dfrac{\Sigma \bar{L}_i}{N} = 20.94$		$\Sigma(L_i - \bar{L})^2 = 1.31$

$$\sigma_L = \sqrt{\frac{\Sigma(L_i - \bar{L})^2}{N - 1}} = 0.433$$

$$\sigma_{\bar{L}} = \delta\bar{L} = \frac{\sigma_L}{\sqrt{N}} = 0.153$$

_____

We then report our result by rounding the standard error to 1 significant digit, rounding the mean value to the same decimal place, and writing it in the appropriate form:
$$L \ = \ 20.9 \pm 0.2 \ m.$$

In any given experiment, when reporting a quantity, we choose for the uncertainty either the absolute uncertainty associated with the measuring device or the standard error, whichever is larger.

Combining answers with uncertainties:

1. Determine the uncertainty expression first and solve for the absolute uncertainty.
2. Round the uncertainty to 1 significant figure.
3. Examine the number. Keep the same number of places after the decimal in the number as you have in the uncertainty.
   e.g. An automatic fit to data gives a slope of 2.7061 with an uncertainty of 0.005611. The uncertainty is rounded to 0.006 (1 significant figure). This value has three places after the decimal so the value of 2.7061 is rounded to 2.706 giving a final result of 2.706 ± 0.006.

When no uncertainty value is provided:

When multiplying, dividing, or applying a mathematical function (ex. trigonometric) with any quantity that does NOT have an uncertainty value written, it is generally understood that the number of significant digits in the answer will remain the same as that of the quantity with the fewest number of significant digits, e.g. $45.5/24 \ = \ 1.9$, where only two significant figures in the answer are kept.

When adding or subtracting, the answer will have the same number of digits after the decimal as the quantity in the function with the fewest number of digits after the decimal, e.g. $2.981 + 0.2 = 3.2$ where the result keeps only one digit after the decimal.

Expectation in the lab write up:

Data as entered in tables are considered raw data and these entries will not be penalized for mistakes in significant figures rules. Answers given in questions are expected to be written with the correct significant figures obtained by following the rules outlined above.

_____

Graphing Summary

Error in a Straight Line Graph
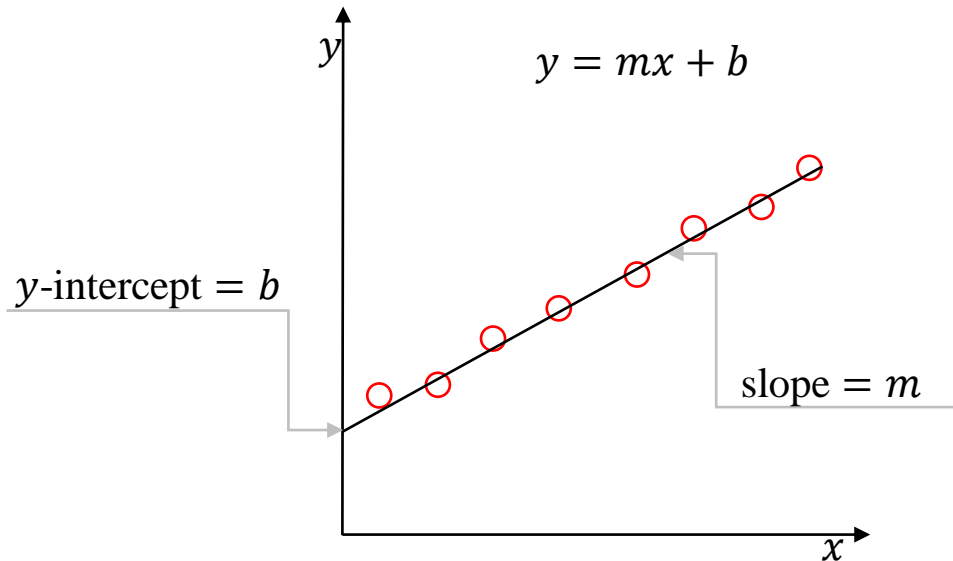
A straight line graph is described by the equation $y = mx + b$. The slope (m) and *y*-intercept (b) can be determined by a statistical treatment known *as linear regression*. The slope and intercept of a straight line and their errors can easily be determined using mathematical software, such as *Graphical Analysis*.

_____

Use of Software

Graphs will normally be drawn with the software package Graphical Analysis.

A graph submitted with your lab report should have the format shown at right:

- label each axis *(double click axis label in data table)*
- title *(double click in white space)*
- fit box displayed with uncertainty *(the standard deviation)*
- remove connecting lines *(double click in white space and disable 'connect points')*

Mass vs Volume for Aluminum Cylinder

Linear Fit For: Data Set:Mass
y = mV+b
m(Slope): 2.706 g/cm^3
b(Y-Intercept): -0.05346 g
Correlation:1.000
Std. Dev. of Slope: 0.005611 g/cm^3
Std. Dev. of Y-Intercept: 0.1072 g

Drawing meaning from your results

The slope and intercept of your graph have physical meaning. To determine the meaning of your slope or intercept compare the physical equation to the equation for a straight line. For the graph shown above:

Physical Equation: $M = \rho V$ (M = mass, ρ = density, V = volume)

Equation for a straight line: $y = mx + b$

Comparing these equations, we see
- mass is on the y axis, i.e. $y = M$,
- volume is on the x axis, i.e. $x = V$, and so
- the slope is the density, i.e. $m = \rho$.
- The intercept in this case is zero, i.e. $b = 0$.

In the above example, we see $\rho = 2.706 \pm 0.006 \; g/cm^3$.