Lab Report Guide: Acceleration due to Gravity

Written by: Paul S. Jeffery

Last Updated: January 2021

This document aims to cover how to write a standard formal lab report in the Department of Physics at the University of Toronto. Before reading the rest of this document, one point to keep in mind is to always inquire with your TA about any additional specifications/requirements for your particular lab. This document is a general guideline, but sometimes you may be required to include additional sections/analyses to account for the specifics of your experiment(s).

Abstract

The abstract should be at most a few lines long and should summarize the key findings, and the main principle of your experiment. For example "In this experiment the motion of a falling object was studied in order to determine the acceleration due to gravity. By measuring the time it took for a metal sphere to fall from various heights the value for g was found to be 9.87 ± 0.06 m/s^2. This value was found to agree to within 0.6 % of the theoretical value of 9.81 m/s^2, thus through the experimental method employed the constant was successfully determined."

1   Introduction

The theory and equations relevant to your experiment should go here, with sufficient detail to explain all that you will be doing in your experiment and analysis. For instance in this hypothetical experiment where we are looking at basic kinematics we should include a few lines on the relevant kinematics theories, and equations. Be sure to define the variables in your equations. Then we should state the purpose of the experiment in at most a few lines, covering what we intend to do in the lab. For example:

"A free falling object is one solely influenced by gravity such that it will experience constant downward acceleration. Kinematics is the sub-field of physics concerned with bodies experiencing such constant acceleration, and yield equations of motion that can be used to describe the behaviour of such objects. One of the key kinematics equations is:

$$\Delta y = v_0 t + \frac{1}{2} a t^2 \tag{1}$$

where Δy is the distance travelled over time t given initial velocity v_0 and a constant acceleration a. For a falling object a is the acceleration due to gravity g, a constant with value of approximately 9.81 m/s^2 everywhere on Earth.

The purpose of this exercise is to experimentally determine the constant g, the acceleration due to gravity, by analyzing an object set into free fall. Specifically, a metal sphere will be dropped from a series of different heights, and the time taken to fall a given height will be measured. These measurements will be fit with equation 1 to yield a slope proportional to the acceleration due to gravity."

2   Materials and Methods

This section should guide the reader through how the experiment was performed and what equipment was used. Almost the entirety of the lab manual should be summarized between the Introduction and this section.

2.1   Materials

In this section you should have a list of all the equipment used in the experiment, along with any particular notes, such as uncertainty or key operational settings. For example:

Equipment:

- Magnetic release mechanism

- Timer switch plate

- Steel ball (diameter 12 ± 0.5 mm)

- Ruler (uncertainty ± 0.5 mm)

- Retort stand

- Timer (uncertainty ± 0.0005 s)

- 4x Banana cables

2.2   Methods

This section should guide the reader through what you did for the experiment with sufficient detail that without reading the lab manual the reader should be able to replicate the experiment that you performed. That being said this section usually does not have to be overly long, so be as concise as you can be. You can use either numbered steps or paragraphs to explain the procedure, and can include diagrams and figures if it helps explain the experimental setup. For any figures or diagrams a clear caption should be included that explains what the figure shows. For example:

"The magnetic release mechanism was attached to the top of the retort stand, and the timer switch plate was aligned under the release mechanism. Both the switch plate and the release mechanism were connected to the timer using the banana cables, and the steel ball was affixed to the magnetic release mechanism. Figure 1 shows the assembled experimental

Figure 1: Experimental setup used for this exercise. A brief comment about the setup that you wish to make clear can also be included here.

setup. The height of the ball above the timer plate was measured using the ruler. Pressing the trigger on the timer started the timer while stopping the power to the magnetic release mechanism, causing the ball to drop. Once the ball makes contact with the timer switch plate the timer is stopped, yielding a measurement of the time taken by the ball to travel the measured height. The magnetic release mechanism was lowered, its new height was measured, and the process was repeated 25 more times."

3   Data and Analysis

Throughout this section the measured data that you recorded will be presented, and then your analytical method, taking the raw data and transforming it into your final results, will be explained. You can divide this into subsections, or keep it together as one section.

For the data portion, the relevant data should be presented in some fashion. This could be a table (with the table covering no more than a page), or more likely a figure that plots the measured data. You want to **avoid redundancy** with your data in your report. If you feel that you need to include data tables despite also having a plot with the data, the tables can be included in your appendix (an example of this is shown). Additional measurements, such as those you need to make only once about some property of the setup should be included in either a separate table, if you have multiple of this type of measurement for example, in a paragraph, or in a bullet point. The data should be presented along with a few lines stating what the data is. If there are any notable outliers in your data, you should draw attention to them, and explain why you may have deemed them to be outliers and filtered them out

from your analysis.

For the analysis portion, you should begin with your raw measurements and work through you process of analysis, with reference to what equations you're using as you go. If you have calculations, they can be included in your appendix as sample calculations, and your uncertainty propagation can go in the appendix as well. The code you used to analyze/fit your data can also be included in the appendix. In essence what is included in your appendix should be extra info that is not essential to your report, and your report should be complete even if the appendix is not read. The analysis section should ultimately take the reader from your raw data to your results. Remember to consider significant digits, and always include uncertainty and units with your values. For your fits, make sure to comment on two goodness of fit parameters, with reduced χ^2 as one of them. Additionally report how your value of reduced χ^2 compares to the ideal value of 1, and what your value, if it differs from this, might imply about your fit.

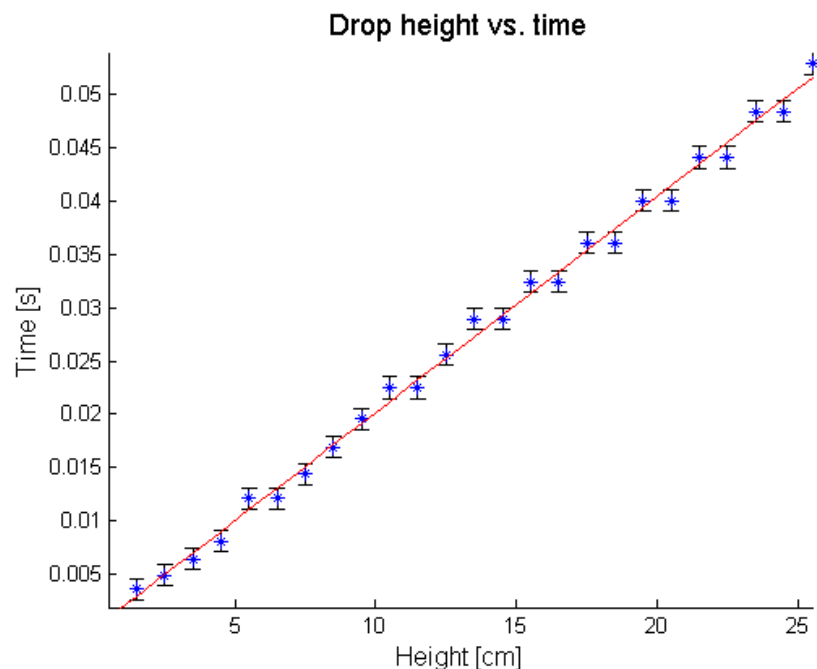Overall, an example for this section is as follows:

Figure 2: Plot of height and time squared data. Include specifics such as "The errorbars are shown in black, and the fit of the data is included as the red line." If the errorbars are too small to be seen, indicate it with the figure, if you don't mention that the errorbars are too small to be seen and they don't appear to be present you will lose marks for not having errorbars. Make sure the values and labels on the plots are large enough to be seen clearly, and always include labels and units.

"The height and time data measured in this experiment are plotted to yield Figure 2. Following this, the plotted data is fitted using equation 1, with the initial velocity component of the equation set to 0 m/s. This led to a fit with slope of 2.03 ± 0.03 x 10^{-3} s^2/m, and an intercept of -9.8 ± 39 x 10^{-5} s^2/m. The R^2 of this fit was found to be 0.996, and the reduced

χ^2 was found to be 0.98, which is very close to the ideal value of 1, indicating that the fit of the data is good. Rearranging equation 1 to determine the acceleration due to gravity from the slope of the fit, the value can be calculated as:

$$g = \frac{2}{slope} \tag{2}$$

which yields an experimental value for g of 9.87 ± 0.06 m/s^2."

4   Discussion and Conclusion

This section has a few focuses. You should report your final value(s) that address the purpose of the experiment, and discuss both the precision and accuracy of this result. The precision of your value is determined by the relative uncertainty of your result (whether the theoretical value agrees to within uncertainty of your final value), while the accuracy is determined by the % deviation from the theoretical/expected value. In this section you should address any questions posed by the lab manual, and these answers should be in full paragraph discussions about the topics rather than as question-answer pairs. Some questions might require doing some research to find appropriate values or concepts to answer the posed problem. In essence treat the questions as topics rather than like homework questions and make sure to address them all. Finally, go over sources of experimental error, and ways to minimize it in the future. **Human error is not an acceptable source of error** as it is a mistake not an experimental error. For instance stating that human error may have affected how a ruler was used is not useful, but stating that reaction time or parallax error that could not be systemically corrected for are acceptable. In essence error should be **unavoidable** problems that **likely** led to a **non-negligible** deviation in the results. The order of this section does not matter, use your judgement to present the clearest and most concise results. In the following example, the questions for discussion are: 1) What was the experimentally determined acceleration due to gravity? 2) Did you value deviate from the theoretical value of 9.81m/s^2? 3) Does the acceleration appear to be constant? 4) How would your results differ for a heavier sphere? 5) How would your results differ for a lighter sphere? The conclusion should restate your main result and state if your experiment was successful. An example of this section is as follows:

"In this experiment a freely falling mass was used to explore the acceleration due to gravity. Specifically, the time that a small metal sphere took to fall from a series of different heights was measured, and the acceleration due to gravity was found by fitting the height and time squared data to equation 1, a kinematics equation that characterizes the one-dimensional motion of a constantly accelerating object. From the fit of this data, the acceleration due to gravity was found to be 9.87 ± 0.06 m/s^2. This experimental value was found to be both accurate and precise, as it agrees with the theoretical value of 9.81 m/s^2 to within 0.6 %, and the theoretical value is within the uncertainty range of the experimental value.

This experimentally derived value agrees with the expectation for the acceleration due to gravity to be constant, evidenced by clearly the linear relation shown in Figure 2, and the

excellent reduced χ^2 value found for the fit of the data. From theory it is known that the mass of an object does not affect its acceleration due to gravity, hence a heavier or lighter mass are expected to accelerate at the same rate as the metal sphere studied here. The exception to this would be a mass with a high enough coefficient of drag, either through a large surface area or small mass, that air resistance is no longer negligible. Under this condition air resistance would lead to a decreasing acceleration with velocity, resulting in an experimentally derived value for g that underestimates the true value of the constant.

Two potential sources of experimental error exist in this experiment. The first of these is a lag between the start of the timer and the release of the metal sphere. A relative delay in the former would serve to shorten the time reported for the sphere to fall, increasing the value of g, while in the latter the opposite effect would be observed. The second potential source of error arises from a potential delay between when the sphere makes contact with the timer switch plate and when the timer is stopped, with a delay leading to an increased measurement time. To account for these possible sources of error the equipment should be calibrated against external sources in order to assess the potential influence they might have on the final results.

In conclusion the acceleration due to gravity was found to be 9.87 ± 0.06 m/s^2, which deviates from theory by less than 1 %, and contains the theoretical value within its uncertainty range. Thus this experiment was successfully able to analyze an object undergoing free fall to experimentally determine the acceleration due to gravity."

5   Final Notes

This is not a section of your report, this is just some additional comments to help you write a lab report. As stated above, you should inquire with your TA about any variations from these guidelines they might want for your report. That being said, unless otherwise told, what is laid out in this guide should be the basis of your reports. Your lab report should not go over the page limits set by the course instructor, and should ideally be as clear and concise as possible. For example the example part of this report takes only slightly over 3 pages, including a large data table and a few figures. Quality work is better than a large quantity of work. Please always include your name and student number, along with your that of your partner if applicable, and the name of the experiment you are doing. Remember to always report values with units, significant digits, and uncertainty. Good luck on your future reports.

References

Any references used for this lab report should go here.

Appendix: Data Tables

You can put extra data tables here if for some reason you need to. For example:

Table 1: Measurements of initial height and the time it took for the sphere to drop

Height [cm] $\pm$ 0.05	Time [s] $\pm$ 0.005	Height [cm] $\pm$ 0.05	Time [s] $\pm$ 0.005
0.5	0.03	13.5	0.17
1.5	0.06	14.5	0.17
2.5	0.07	15.5	0.18
3.5	0.08	16.5	0.18
4.5	0.09	17.5	0.19
5.5	0.11	18.5	0.19
6.5	0.11	19.5	0.2
7.5	0.12	20.5	0.2
8.5	0.13	21.5	0.21
9.5	0.14	22.5	0.21
10.5	0.15	23.5	0.22
11.5	0.15	24.5	0.22
12.5	0.16	25.5	0.23

Appendix: Sample Calculations

You can put sample calculations, including those for the propagation of error, here. Each should be captioned with what the calculation is for.

Appendix: Code

You can put your analytical code here if for some reason that is required or you feel it is worth including.