# Lab 5 manual: Archimedes Force

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For PHYS 1111L and PHYS 2212L

(Lab outcomes: producing the plot with error bars, doing fit, linear regression, and finding reduced in Excel)

## Abstract

This experiment uses the Archimedes principle to measure the density of the submerged body using two different methods – the original one used by Archimedes himself, and the method that minimizes measurement errors. Additionally, plotting and data fitting skills are honed, goodness of fit criteria using (from least squares fitting) is introduced.

## Introduction

The good place to start looking for the general information about Archimedes principle is [1]. Try to avoid citing Wikipedia as it’s not a reliable source of information in general; it’s also a good start to look for other courses – see references under the wiki articles.

Whether a trendline fits the data well is determined by the so-called reduced value. Note that there are few things called so be careful not to mix them up.

## Experimental Setup

The schematic for this experiment is shown in Figure 1 and includes the body (Figure 1b) that is attached to triple-beam scale (Figure 1a) and a measurement cup (Figure 1c). Graduated cylinder (Figure 1d) is used to measure the water overflow.

a)

c)

Triple-beam Scale

Liquid

b)

d)



Figure 1: The experimental setup schematic. A triple-beam scale (a) is used to measure the body (b) weight in air and when submerged in liquid in measurement cup (c). Water overflow is measured by graduated cylinder (d).

### Procedure

PART I

For part 1, we will use the scales, an irregular aluminum shape, measurement cup and a graduated cylinder. First, weigh the metal shape. You can use the systematic and statistical errors from the measurements lab or estimate them again. For systematic error, use the manufacturer stated accuracy. For the statistical, do the 5 measurements: average is shape’s weight and stdev is the error. Or think about how you can estimate that based on previous experience (check with lab instructor if unsure).

Fill the measurement cup until water starts to overflow. Wait for the excess water to discharge fully, then place the graduated cylinder to collect the overflow and fully submerge the aluminum shape. Think about the systematic and statistical errors for the cylinder (if you are unsure about the statistical error, repeat this step 5 times).

Now you have mass and volume, and density can be calculated. Remember to treat all the errors correctly.

For 2211L, treat statistical and systematic errors separately and show the density with 2 errors as syst and stat.

**1111L only**: combine all systematic and statistical errors together into a single error (separately for mass and volume) using . Show result with a single error, no need to specify which one it is (it’s neither statistical or systematic but rather all combined).

PART II

Choose 5 different objects[[1]](#footnote-1) from the provided that are made from the same material (hint – same color most likely means same material. Check with your instructor if unsure). Tie the string to each object as needed or use a holder provided. Attach to the bottom hook of the scales. First, weight in air. Then, hold the cup with water carefully around the object so it’s not touching the walls or the cup’s bottom, and repeat the weighing. Record both the mass in air and in the water. Think about the statistical and systematic errors. Plot vs (), slope is the density. Water density is unity. Combine all errors into single one as above and use as error bars (x and y!). for x error bars, what will be the error values? How the is involved?

## Experimental Data

Organize the results of the measurements in tables such as Table 1 and Table 2. The error can be listed in a different column or as value ± error unit. Don’t include every single measurement here, only relevant means, stdev etc. if you measured same values several times. All data values may be included in the Appendix if desired and needed.

Table 1: Experimental data for part 1.

|  |  |
| --- | --- |
| Mass, g | Water volume, |
|  |  |
|  |  |

Table : Experimental data for part 2.

|  |  |  |
| --- | --- | --- |
| Object # | Mass in air, g | Mass in water, g |
|  |  |  |
|  |  |  |

Provide description about each entry as needed, don’t just leave the table without text in this section. Organize well so that data takes less space, but everything needed is included.

## Theory

Show the equation that you need to use for part one of this lab. Remember to show the equation that you will use for error propagation. All sections can use simplified formulas for this lab; only PHYS1111L can combine all errors into single one (added in quadrature) to propagate – PHYS 2211L should treat systematic and statistical errors separately.

For the part two we need the basic equation for the Archimedes law:

written using the density of the liquid, volume of the body and the acceleration of free fall. From equation 1, we can expand it and turn into equation 2:

From eq. 2, if we plot vs (), then the slope of the fit line (trendline) is the body density that we seek. *Use scatter plot, dots only!!*

**Extra credit**: derive result of equation 2 by starting from forces acting on the submerged body. Draw the free-body diagram and go from there.

When plotting (place the plot in the analysis section!), remember that axes need to be labeled. If error bars are so small so that they can’t be seen in the plot, mention them in the plot description and/or caption. Plot is also a ‘Figure’, don’t use any other names.

## Analysis

Find the density of the submerged body in both parts using corresponding equations. For part 1, compare the result with the know density for Al (use reference to the source) and do the %discrepancy.

For part two, true density is not known – use your result to suggest the material that the weights can be made from.

From the plot, we also need to get the error on the slope and the ‘goodness of fit’. The value that most software provide is not a sufficient measure (explained in the lecture). Use the provided template to find the reduced value (. See Appendix for additional information.

To get the error on the slope, we will use linear regression tool in Excel (for Google sheets, see <https://www.statology.org/linear-regression-google-sheets/> ). Go to Data menu ribbon and choose ‘Data analysis’. Select Regression option, for input X and Y range select the same data you used for the plot and click OK. We are interested in the x variable value and its error as shown in Figure 2.

Table

Description automatically generated

Figure 2: The linear regression relevant values.

If your Excel doesn’t have this button, it needs to be activated – go to “File” menu, ‘Options’, Add-ins, Manage Excel add-ins and click “Go” button. Check the ‘Analysis ToolPak’ and hit Ok. The option should be in the Data menu.

## Conclusion

Discuss the results of part 1 and how well did your result match the known value. What are the reasons that the march is so close/not close? How can this be improved?

For part 2, is the error you calculate higher than part 1 or lower? Why is that? How

# References

|  |  |
| --- | --- |
| [1] | E. Gregersen, "Archimedes’ principle," Encyclopaedia Britannica, 29 05 2019. [Online]. Available: https://www.britannica.com/science/Archimedes-principle. [Accessed 18 05 2022]. |

## Appendix

The sample below shows you an example of calculation in Excel. Similar steps can be taken in other spreadsheet programs. You are welcome to use professional data analysis software that provides the and the errors on fit parameters (for extra points!). Delta velocity in the figures is the error in the velocity parameter.

Plot the data in Excel using ‘scatter plot with only markers’ as velocity vs. time (e.g. vertical axis is velocity and horizontal one - time). Label the axes. Include error bars for the velocity – time is considered ‘perfect’ as measured by PC. To set the error bars, click on one of the data points and choose the ‘Layout’ bar on the main menu. Choose the ‘Error bars’, then choose ‘More error bars options’. Mark ‘both’ in directions part, then in ‘error amount’ select ‘fixed value’ and enter the value for the velocity error determined earlier. From the resulting plot, select and remove the horizontal error bars that are not needed as the time error is much smaller than the time scale used (FOR THIS EXAMPLE ONLY!).

From the graph it is obvious that the set of data has a linear trend. To find the best fit for this set of data, right click on one of the data points and select “Add Trendline”, choose “Linear” trend type and check the “Display equation on chart” option. The equation describes the line (best fit found) for your set of data. Make sure you uncheck the ‘Display R-squared value’ option as it is not same as 2. The slope of this line is your average acceleration. You also need to find the error of the slope (as linear regression).

To estimate how close the best fit line is to the experimental data, you should perform the Chi-Squared Test. For that you should use the theoretical equation of the best fit that you got from the trendline and calculate the theoretical values of velocity. Then calculate the squared difference between the theoretical and experimental values as:

Divide the obtained value by the number of degrees of freedom:

Screenshot samples below indicated how to do this in Excel. You may also use the excel file attached to this manual or distributed in the lab session. (Note that if you take any materials/plots etc. from this manual, you must reference them as well, same as any external source. On the other hand, ‘common-knowledge’ formulas like d=vt and similar don’t need any references. )

In all steps, use proper number of significant digits!

First, define the theoretical value by typing in your fit results:

Graphical user interface, application, table, Excel

Description automatically generated

Then define the square of the difference between the measured and theoretical values.

Graphical user interface, text, application, table

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Sum all values of chi1 column. Divide chi2\_sum by the degrees of freedom (ndf, number of data points minus the number of free parameters of the fitted function (in our case ndf = nvalues – 2, as line has two fitter parameters, a and b). DO the linear regression. Include these values on the final plot (see example).



Quick note: if your 2 value is much larger then 1, you may increase the error (and the error bars size) for the velocity, make sure you clearly state that in you report. If the value is much smaller then 1, you may NOT reduce the error, but comment on why it is larger than the actual spread of your data points.

1. You can choose different masses or a set of same or similar masses and just increment – use one, two, three together and so on. All measured masses must be different! [↑](#footnote-ref-1)