

225L Acceleration of Gravity and Measurement Statistics

Introduction: The most important and readily available source of acceleration has been gravity, and in particular, free fall. One of the problems with a direct measurement of the acceleration of gravity is its relatively large acceleration, which made accurate vertical position vs. time measurements over short falls difficult before the advent of modern electronic measurement systems.

In the present experiment, we will determine the acceleration of gravity of a freely falling object and use a photogate to measure the very short time intervals between equally spaced¹, dark bands on a clear plastic rectangle called a Picket Fence (see figure 1). When the Picket Fence passes through a photogate, the device notes when the infrared beam of the photogate is blocked by a dark band and measures the time elapsed between successive “blocked” states. The software uses these times and the known distance from the leading edge of a dark band to the next to determine the velocity of the picket fence as it falls through the photogate. Due to the acceleration of gravity and resulting increase in speed, the intervals between the on and off times get shorter and shorter as the picket fence falls thru the photogate light beam.

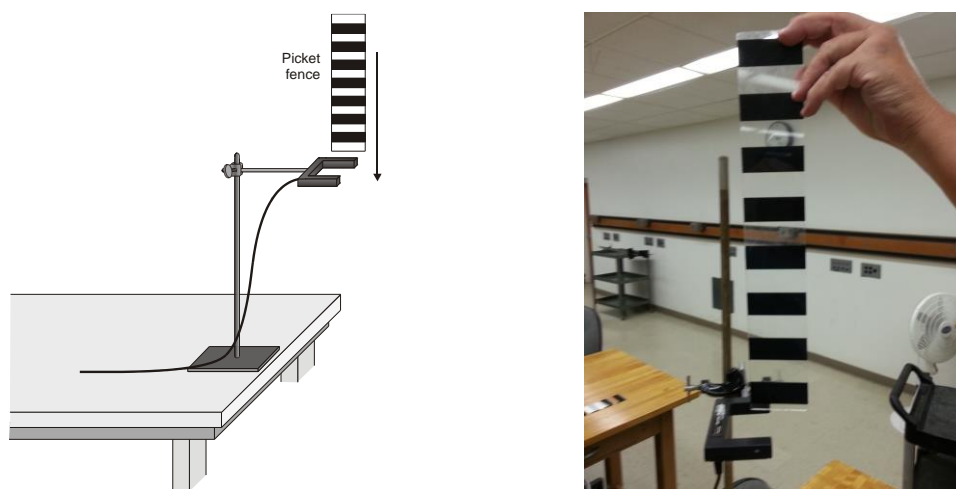


Figure 1. Diagram and photo of picket fence and photogate apparatus. Be sure to insert back edge of picket fence far enough into the photogate to break the optical beam and to drop it vertically.

Summary of the experiment: In this lab experiment, we will 0.) setup and test the Logger Pro Software to display position, velocity, and acceleration and corresponding fits to the data with the fit parameters displayed on screen as shown in figure 2. (This should already be done in a file for you. If not, reference procedures 1-8 as necessary in the accompanying Vernier software writeup). 1.) Obtain a “good” value of g for a single run (out of 3-5 or so trials) and compare the g and v_0 values obtained from the position, velocity, and acceleration plots using fits to the data. Take a screen shot of the data displaying all three graphs and paste it into a word document. (see following for details). 2.) The main event. Generate two histograms similar to the example in figure 3, one for g and one for v_0 (you will have to experiment with manually adjusting the number of bins to get a good histogram). Drop the picket fence through the photogate 35 successful times (without it touching the edges as it passes through) and *record the values of g*

¹ The picket fence is a rectangle 38.8 cm long and 6.5 cm wide. The width of the dark bands and transparent regions is 25mm. The distance from the leading edge of a dark band to the next is 50mm.

and v_0 in two columns in a hand written data table on college ruled (blue book) paper. (The hand written data table *MUST* be turned in with your lab report, no exceptions). You will transfer the data to an Excel spreadsheet *ONLY AFTER* recording all the data in the hand written table. Have one lab partner drop the picket fence and read off the m and b values from the linear fit to the velocity vs. time graph, and the other lab partner write down the values in the hand written table. Make screen shots of the histogram for g and for v_0 and paste into your Word document.

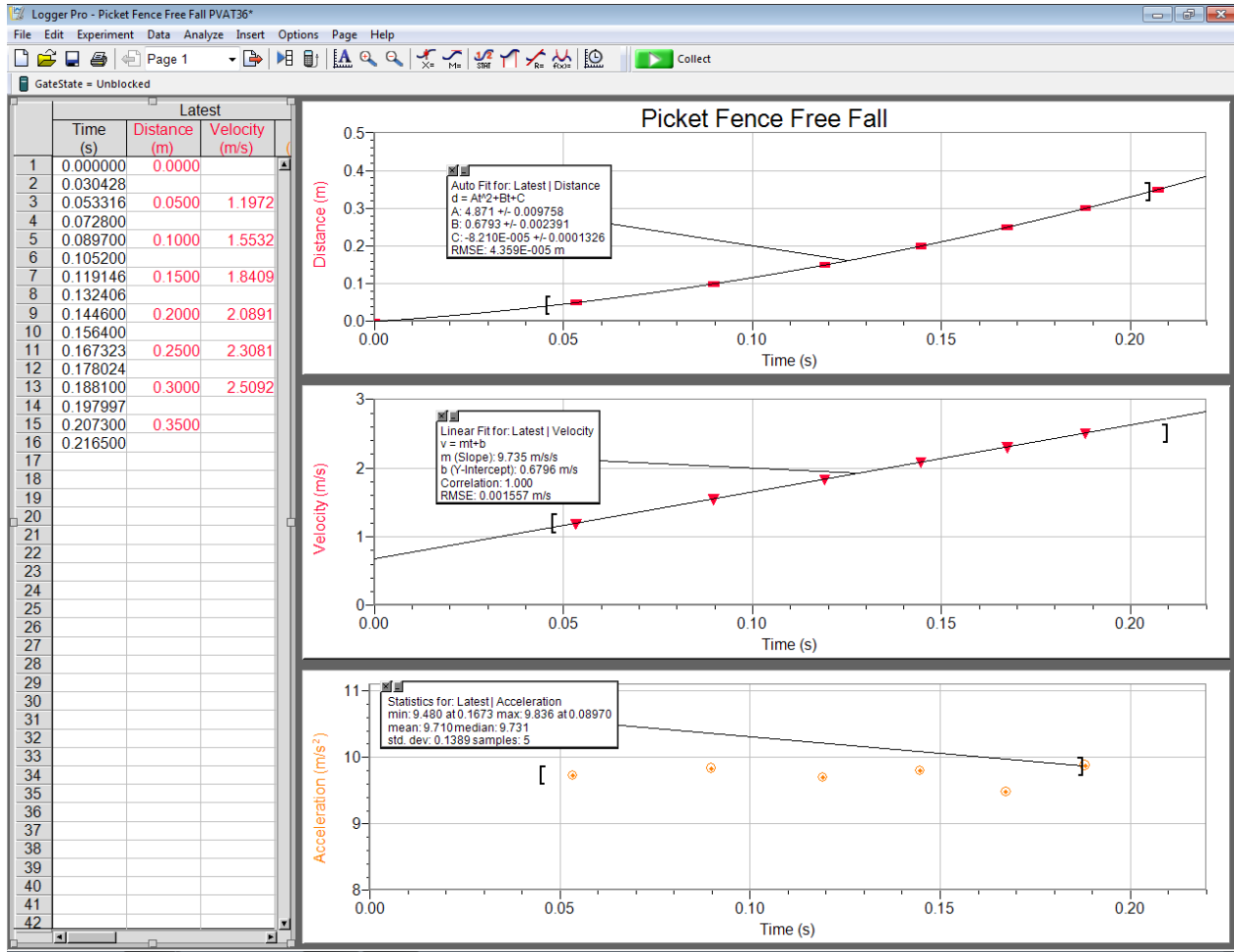


Figure 2. Example position, velocity, and acceleration graph screen shot showing the scale setup and the least square fits to the data. Note the fit parameters and their standard deviations in the inset boxes. For this run the velocity vs. time graph gave a value for the slope $m = g = 9.73 \text{ m/s}^2$. The position vs. time graph gives $2A = g = 9.742 \text{ m/s}^2$. The acceleration graph gives a mean value of 9.71 m/s^2 , but is only based on 5 data points. The left [and right] brackets indicate the range of the data that is fit. In the position and acceleration graphs example above, the right bracket] is not far enough to the right to include all the data, and the last data point has been inadvertently excluded. Be sure that your left [and right] brackets include all the data in between the [] brackets in all your fits.

Lab Report: Your lab report should contain 3 screen shots. 1 similar to figure 1, and 2 similar to figure 3, (one for the values of g, and one for the values of v_0). It should also have your hand written data table, and any comments, answers to questions and hand written calculations that

you perform. Answer questions from the following writeup and the accompanying Vernier software lab writeup as time permits. All of these items should be stapled or taped and handwritten into your exam blue books as appropriate and submitted as a single lab report for each lab station. Both lab partner names and experiment title should be on the cover page of the blue book, along with the date. Be sure to write a summary of the results for the experiment at the end. Additional details of this exercise follow.

0.) Initial software setup and hardware test

Open the Logger Pro software file called: "Free Fall.cmb1". It should look similar to figure 2 above and may or may not have data displayed in it already. There should be inset boxes for the data fit parameters. Make sure the position, velocity, and acceleration scales on your graphs are the same as the vertical and horizontal scales in the example figure 1 below, and insure that you select the manual scale option if you need to adjust them (the default is auto scale, which does not display the data with sufficient magnification and tends to change each data run).

Click the green collect data button at the top of the Logger Pro menu bar. Note that data is not collected until the picket fence breaks the beam. Test the data collection by dropping the picket fence through the beam. The fit parameter values and graph should update each time you click the collect button and drop the picket fence through the photo gate timer. You can wait as long as you want after the collect button is pressed before you drop the picket fence through it.

1.) Obtain a good value of g for a single run and compare the g and v_0 values obtained from the position, velocity, and acceleration plots using fits to the data. Take a screen shot of the data displaying all three and paste it into a word document.

Make sure the photogate is connected and practice dropping the picket fence through the photogate a few times without it touching or nicking the side (when that happens, the contact friction slightly slows down the picket fence, and the value for g is too low). The picket fence is best dropped when held from the top center with 2 fingers. Holding it off to one side is a source of error due to the resulting tilt and the picket fence passing through the timer at an angle (can you see why this causes an error? Can you calculate the tilt error?).

For 1 trial where you find a "good" value² for g from the slope of the velocity vs. time fit line (should be in the range $g = 9.75- 9.85$), take a screen shot of your 3 graphs showing the fit lines and the values of the fit parameters. Identify the fit parameters with g and v_0 for the position and velocity graphs. Use a quadratic fit for the position, a linear fit for the velocity, and the mean value of the data for the acceleration, as shown in figure 2. The mean value and standard deviation of the selected data range is calculated and displayed when you click on the stat button on the top of the screen (see figure 1). **MAKE SURE YOU HAVE PROPERLY SELECTED ALL THE DATA TO INCLUDE IN THE FITS AS NOTED IN THE FIGURE 2 CAPTION.** Report the values of g and v_0 and their standard deviations obtained from the 3 different methods (note that you only get g and no v_0 for the acceleration plot). Comment on any similarities or differences between the 3 methods. Which do you think is the most accurate and why?

² The local value of $g = 9.796 \text{ m/s}^2$ for Fullerton. 34°N latitude and elevation of $155+90 \text{ ft.} = 245 \text{ feet, 6th floor.}$
<http://www.sensorsone.com/local-gravity-calculator/>

2.) **Generate two histograms, one for g and one for v_0** from 35 successful trials using the values recorded in your data table. Enter the two columns of data from your handwritten table into two columns in Excel. Follow Vernier software Evaluation of Data procedures to generate histograms. Refer to Vernier writeup as necessary (copied below)

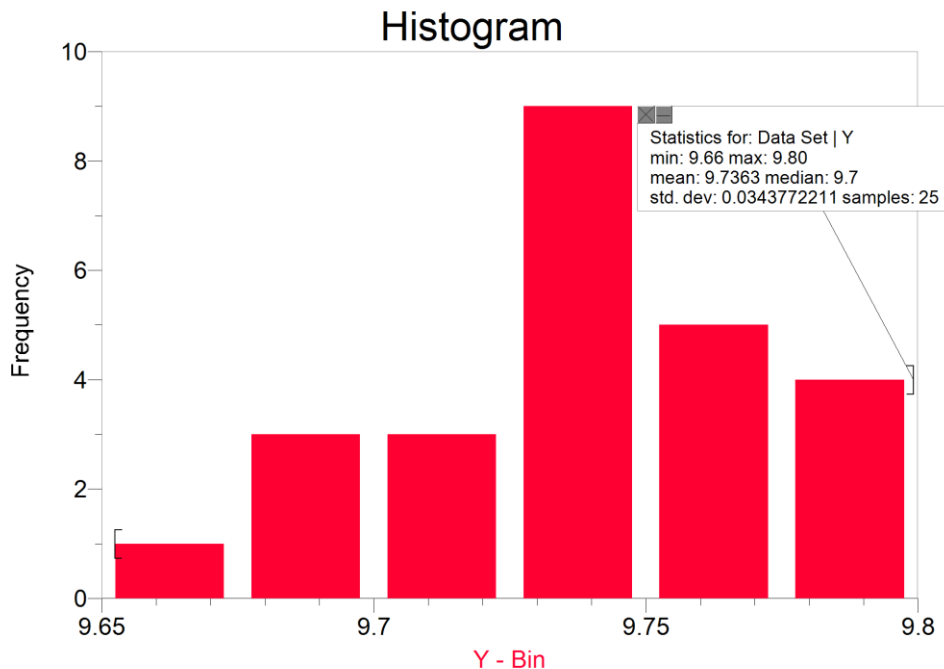


Figure 3. Example Logger Pro histogram of g values for 25 samples with statistics displayed. You should obtain 35 values for g and v_0 . Note we have selected the bin range and number of bins so as to display the “best looking” histogram (6 or 7 bins usually looks good for this few data points).

5. Begin the data-collection program as you did before and drop the picket fence through the photogate another 35 times, bringing the total number of trials to 35. Since you are now investigating the variation in the values of g AND v_0 , you need only record the value of the slope and intercept in your hand written data table of the best-fit line to the velocity-time graph for each trial.
6. (SKIP TO 8 FIRST AND COME BACK) Close Logger Pro file. Disconnect the photogate from the interface. Open a blank file (double click the Logger Pro shortcut.) The program should open with a table of X and Y columns. Paste the 35 trials into the Y column. To facilitate the evaluation of the data you have obtained for the 35 trials you have performed, and enter your values of slope into a new Logger *Pro* file.
7. Determine the average value of g for all 35 trials. How does this compare with the value you obtained for the first 5 trials? In which average do you have greater confidence? Why?
8. Make a Histogram of g and v_0 . Sort the data in ascending order in each column separately, this is best done in Excel. Delete the graph of Y vs. slope. Now construct a histogram to display the frequency of the values of g you have obtained. To do this, choose Additional Graphs ► Histogram from the Insert menu. In your discussion, you will decide how best to configure the features of the histogram so as to represent the distribution of your values in the most meaningful way. Also, repeat this procedure to make a histogram for the v_0 values.

9. In what range (minimum to maximum) do the middle 2/3 of your values fall? In what range do roughly 90% of the values closest to your average fall?
10. One way to report the precision of your values is to take half the difference between the minimum and maximum values and use this result as the uncertainty in the measurement. Determine the uncertainty in this way for each range of values you determined in Step 9.
11. In what place (tenths, hundreds, thousandths) does the uncertainty begin to appear? Discuss whether it is reasonable to report values in your average beyond the place in which the uncertainty begins to appear. Round your average value of g to the appropriate number of digits and report that value plus the uncertainty.

Take screen shots of both your g and v_0 histograms and paste into your Word document, be sure to format the size to not be too big or small. Draw vertical lines indicating the mean, mean plus 2 standard deviations, and mean minus two standard deviations on both the g and v_0 histograms. This represents 90% probability that the data lies in that region if one has a gaussian random process.

Additional Questions for your report:

See Questions in accompanying Vernier software lab writeup.

(answer as many as you can if there is any additional time available, otherwise ignore these questions)

Report:

When you are done with items 0.) \rightarrow 2.), properly format and resize your screen shot graphs in the Word document along with any typed results and comments you may have (computer typing is not necessary, especially if it takes you longer than handwritten comments). Take the file to the front and have the instructor print it. Tape or staple your computer graphs and hand written comments or answers to questions in your blue book. This may require a little bit of manual cutting of the graphs to fit the blue book pages. Both lab partner names and experiment title should be on the cover page of the blue book, along with the date. Be sure to write a summary of the results for the experiment at the end.

Appendix:

Effects of small periodic variations in position vs. time.

Finite difference, numerical approximation to derivatives and errors due to sampling rate.