

One-Dimensional Motion

Object: The objective of this experiment is to explore one-dimensional motion and learn how best to describe the motion of an object. In particular, we will look at the relationships among elapsed time, distance traveled, speed, and acceleration.

Apparatus: Picket fence, photogate, interface device, computer, and *DataStudio* Software.

Foreword

A complete description of the motion of an object must include information about the object's position, velocity, and acceleration at all times. While this information might come in the form of data, a graph, or a function, a combination of the latter two gives a comprehensive picture of the motion at a glance.

In this experiment, we wish to describe the motion of a moving object by plotting graphs of position, instantaneous velocity, and acceleration as a function of time and then obtaining the corresponding functions. It is also our intent to use current technology to acquire the data, make the plots, and determine the functions.

If a train which has a picket fence painted on the side passes you, some thought will convenience you that you can use this picket fence and a timing device to determine the position, velocity, and acceleration of the train at all times. Once this is done you can make plots of the position, velocity, and acceleration as a function of time. Following this you can use your expertise from graphical analysis to determine a function which gives the position, velocity, and acceleration at all times, i.e. $x(t)$, $v(t)$, and $a(t)$. Armed with the graphs we have a good conceptual picture of how the train moved and armed with the functional relations we can confidently answer detailed questions about the train's motion.

In this experiment, the picket fence is on a piece of plastic (rather than a train) and the fence is dropped in order to provide some motion for us to analyze. Hence the motion of the picket fence is that of a freely falling body. Your eye observing the passing pickets is replaced by a photogate, the computer will keep track of the time, and the *DataStudio* software will help us collect the data, plot the graphs, and determine the corresponding functions. It is important for you to realize that we will do a sample calculation by hand of every type of calculation we are going to ask the computer to do. As a result we will know exactly how the computer is determining all of the information in the table of values.

Procedure

Part I. Hardware Set Up

1. The computer should be up and running. Make sure the monitor, keyboard, and mouse are connected to the computer and that the computer is connected to the Internet (so it can access the printer). Make sure the Pasco Signal Interface Box is connected to the computer.
2. Position the photogate so it extends over the side of the table allowing you do to drop the picket fence through the photogate and into a catching device (landing on a backpack will suffice). See **Figure 1**. If you drop the picket fence onto the floor, you run the risk of breaking off a corner. You may want to make a few practice drops just to make sure that everything is properly aligned.

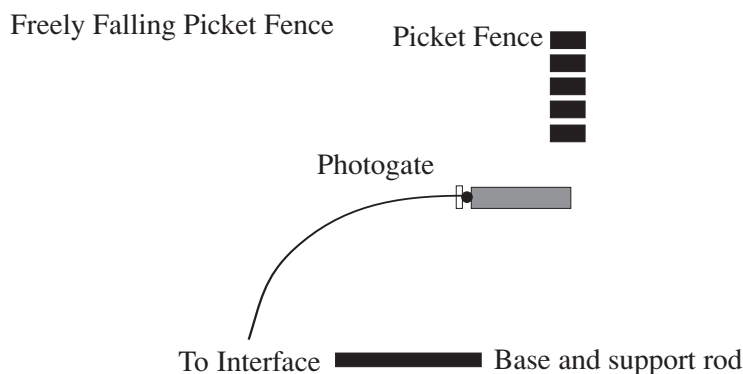

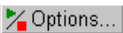



Figure 1

3. Plug the photogate into Digital Channel One of the Signal Interface Box.



Part II. Software Set Up

1. Double Click on the *DataStudio* icon to open the software. If a display appears asking you what you want to do with the software. Click on the “**CREATE EXPERIMENT**” option. At this time, a display will come up which is similar to the Signal Interface Box.
2. *DataStudio* allows you to symbolically set up the equipment, so that the software knows what experiment you are doing, so to begin, from the list of sensors just to the left of the Interface Box window, click and drag the **photogate and picket fence** icon ( Photogate & Picket Fence) and drag it to Digital Channel One (just as you did with the real photogate). This icon should now be “connected” to Digital Channel One by a line.
3. The photogate is used like a stopwatch to measure time. The picket fence is used to turn the photogate on and off at regularly spaced distances. There are six different things that can be monitored with a photogate. We will utilize four of these measurements. To tell the computer this:
 - a. Double-click on the photogate icon connected to the Signal Interface Box to get a popup window labeled “sensor properties.”
 - b. Select the tab labeled “**measurement.**”
 - c. Place a check by the “STATE” options from the list.
 - There should now be a check by *State*, *Position*, *Velocity*, and *Acceleration*.
4. Next, click on the “**constant**” tab. The opaque band spacing should be set at 0.050 meters. This is the distance from the first edge of the dark (opaque) band to the first edge of the next dark band. Confirm this, and click **OK**. You should see an icon for everything we will be monitoring (*State*, *Position*, *Velocity* and *Acceleration*) in the top left window labeled “DATA.”
5. Now, we must increase the amount of displayed significant figures so that when we do calculations by hand, they agree with the computer’s calculations. Adjust all the precision values (number of decimal places) for position, velocity, and acceleration along with their corresponding times (X-Variable **and** Y-Variable) to five (5). This must be done separately for each measurement (*position*, *velocity*, and *acceleration*). To do this, refer to the section of the appendix, “**ADJUSTING THE NUMBER OF DISPLAYED DECIMAL PLACES**” or the help feature of *DataStudio*.

- Next, we will tell the computer to start taking data when the first dark band passes through the photogate, thus setting the first position (0.0m) to the initial time (0.0s). Click on the Start and Stop Options button  at the top of the experiment setup window. This will bring up a sampling options window. Click the tab labeled “**Delay Start.**” In this area, select “**Data Measurement.**” Adjust the other windows just under “**Data Measurement**” to read “*State (Ch1,V),*” “*is below,*” and “*0.50V.*” With this, once the first opaque band crosses the light beam in the photogate and breaks the light beam and the voltage drops, the computer will begin taking data, Click **OK.**
- Now, the computer knows what equipment you are using and when to start taking the data. You still have to tell it how to display the results. We wish to first look at the results in a data table that contains all the useful information. To tell the computer this, click and drag the “TABLE” icon ( Table) in the bottom left of the window to the “**Position**” icon above it in the “DATA” window. A data table should appear with two columns. One for time, and one representing the position at those times. Next, click on the icon representing the velocity and drag it to the **middle** of table that you just created (*Don’t release unless the dotted box is around the entire table*). Do the same for the acceleration. Now there should be three sets of information on the table: position, velocity, and acceleration along with their respective times.

Part III. Collecting Data


So far you have told the computer to record the time when the light is interrupted while you drop the picket fence through the photogate — recall that you have also told it don’t start recording until the light is interrupted the first time — hence this event occurs at $t = 0$. Make sure there is a catching device (box, pad, or backpack) under the picket fence, or it may break when it hits the floor.

- Hold the picket fence above the photogate. It is critical that the pickets are horizontal
- Click on  Start .
- Once the timer starts, drop the picket fence through the photogate into the box.
- Click on  Stop .
- If the picket fence does not fall cleanly through the photogate, delete the failed data run by going to the experiment menu (very top of window) and selecting “Delete Last Data Run” and then repeat the trial.

At this point you should respond to questions 1 through 6.

Part IV. Plotting the graphs

Now we should look at this data in graph format.

- Locate the graph icon in the lower left hand corner of the screen.  Graph Click and drag it to the position icon. You should now have a graph of position versus time. At this point, you will find it convenient to connect the dots on your graph. Refer to the Appendix or the Help feature to learn how to do this. You may also want to vary the maximum and minimum values on an axis in order to get a better look at the data on the graph.

At this point, you should respond to question 7.

2. Now to this same page, add a graph of velocity versus time by clicking on the velocity icon and dragging it to the middle of the position versus time plot you just created (don't release unless the dotted box is around the entire table). At this point you may want to connect the dots and adjust the scale.



At this point, you should respond to question 8.

3. Now to this same page, add a graph of acceleration versus time.

At this point, you should respond to question 9.

Part V. Analyzing the Graphs

We are now ready to use the computer to “curve fit” each of the graphs. Determine the functional relationship for each graph, and compare it to your responses to questions 7-9.

1. Create a Curve Fit for each graph (*Position*, *Velocity* and *Acceleration*).
 - You should use the “FIT” button on the graph toolbar.
 - An icon for each curve fit (*Position*, *Velocity* and *Acceleration*) should be in the “DATA” window after you are finished.
2. Be sure to record these curve fits and their associated constants.
3. After you have generated a curve fit equation for each line, compare the line for the curve fit to the line of the appropriate graph by doing the following:
 - a. To do this for the position graph, bring the position graph into view. From the top left window, click and drag the icon representing the position curve fit  to the *position graph*.
 - b. Compare the two lines.
 - c. If not satisfied with the curve fit (the lines don't match very well) then double click on the icon representing the curve fit in question and the curve fit window will popup and allow you to make changes. Be sure to click  after you modify the curve fit to accept and save the changes.
4. Repeat this comparison for the velocity and the acceleration and their respective curve fits.
5. Once you are satisfied with the comparison of the curve fits to the curves they represent, use the text icon on the graph paper to title each graph and show the equation for each graph.
6. Print the data table and graph page for your report.

At this point you should respond to questions 10 through 13.

Questions

1. Look at the position data in your table of values and comment on what you notice.
2. Look at the velocity data in your table of values and comment on what you notice.
3. Use the position and time information to calculate the first three values of the velocity in your table of values. Show all work and give all reasoning. *Remember, we set the first position (0.0 m) to be taken at 0.0 seconds.*
4. It is appropriate to consider these velocities as average velocities over certain time intervals. Elaborate on this statement.
5. It is appropriate to consider these velocities as instantaneous velocities at certain times. Elaborate on this statement.
6. Use the information in your table of values to calculate the first two values of the acceleration. Show all work and give all reasoning.
7. What mathematical relationship do you expect for the position vs. time plot? For example, is the equation linear, polynomial, logarithmic, exponential, etc. . Use your knowledge of graphical analysis to write the equation for this line and hence the functional relationship between position and time. Show all work and give all reasoning.
8. What mathematical relationship do you expect for the velocity vs. time plot? For example, is the equation linear, polynomial, logarithmic, exponential, etc. Use your knowledge of graphical analysis to write the equation for this line and hence the functional relationship between velocity and time. Show all work and give all reasoning.
9. What mathematical relationship do you expect for acceleration vs. time plot? Use your knowledge of graphical analysis to write the equation for this line and hence the functional relationship between acceleration and time. Comment on the value of the acceleration the computer has calculated. Show all work and give all reasoning.
10. Write the equation displayed for your Position curve fit. Include the values of the constants. Compare this to your response to question 7.
11. Write the equation displayed for your Velocity curve fit. Include the values of the constants. Compare this to your response to question 8.
12. Write the equation displayed for your Acceleration curve fit. Include the values of the constants. Compare this to your response to question 9
13. In the curve fit equations to Position, Velocity, and Acceleration, draw any possible conclusions regarding the constants for each of the functional relationships and how they are related to one another as well as any known physical constants governing the motion of the picket fence.

Challenge

Pass the picket fence through the photogate at a constant velocity and use your knowledge of technology to not only prove that the velocity is constant but also to determine its value.