Physics 161

FREE FALL

Introduction

This experiment is designed to study the motion of an object that is accelerated by the force of gravity. You will also be introduced to the data collection capabilities of Capstone and analysis in Excel. There are three goals for this lab. Learn to acquire data using Capstone, and how to analyze it with Excel. Find an average value for the gravitational acceleration and the standard deviation of the collected data. And finally, discuss why your measurements may be different from the expected value.

Reference

Young and Freedman, University Physics, 12th Edition: Chapter 2, section 2.5

Theory

A free falling object accelerates toward the earth with a constant acceleration equivalent to $g = 9.8\, m/s^2$. The velocity, v, measured in meters per second is therefore changing according to the acceleration. The kinematic equations for a free falling object are:

$$y = y_0 + v_0 t + \frac{1}{2} g t^2 \tag{1}$$

$$v = v_0 + gt \tag{2}$$

The vertical position (height) is represented by y, with respect to time, t, where y_0 is the initial vertical position, v_0 is the initial velocity and g is the acceleration due to gravity. The plus sign in front of the last term in both equations is due to the reference coordinate system used in this experiment. The equation for position, (1), yields a quadratic curve for position vs. time. The relationship between velocity and time is described by Equation (2), this equation describes a straight line with a slope, g and a y-intercept of v_0.

In the case of a bouncing ball, acceleration is constant while the velocity and position change over time. For each bounce, the slope of the velocity versus time graph should yield a relatively constant value of g. To evaluate how constant these values are, you will measure 10 slopes and calculate the standard deviation. The standard deviation measures how much the data deviates from the average value of the set.

Procedure

In this experiment you will use the Capstone motion sensor to record at least 10 bounces. The motion sensor is mounted on the edge of the table facing the ground. The ball is dropped at a position approximately 15 cm from the motion sensor.

Determine g.

1. Check that the Motion Sensor is set to the correct distance range for today's lab. To do this, look at the top of the sensor and set it to the short-range designation (), see Figure 1. If you have trouble later, try switching it to long-range ().

Figure 1: Range selection.

2. Plug the yellow and black wires into the (1) and (2) digital channels, respectively, on the 850 Interface Box.

3. Click on the Hardware Setup icon in the left vertical toolbar. Then click on the left circle in the upper image that correspond to the yellow cable input on your Capstone box, and select **Motion Sensor II**.

4. In the lower box, next to recording conditions, set the sample rate of the **Motion Sensor II** to 40 Hz, see Figure 2.

Figure 2: Sample rate of the Motion Sensor II

5. Double click on the **Pasco Capstone** icon on your computer desktop. Double Click **Graph** under the **Display** menu on the right hand side, see Figure 3.

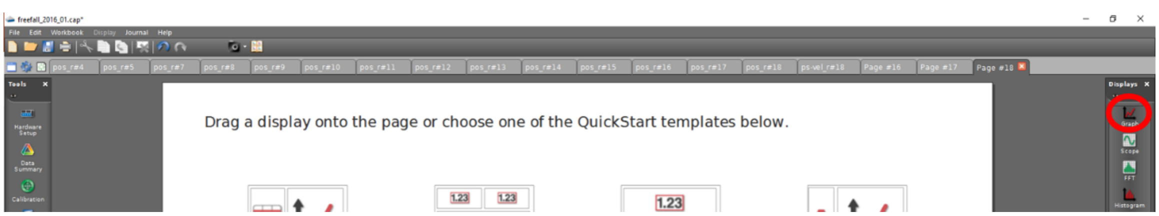

Figure 3: Button to create a graph dispay area

6. Go to the tool bar at the top of the page. Click the **Add New Plot Area** tool to create a new plot area, see Figure 4. Then assign a label for position in the top plot area, and assign a label for velocity in the lower plot area. You should now have two labeled plots in the graph area, see Figure 5.

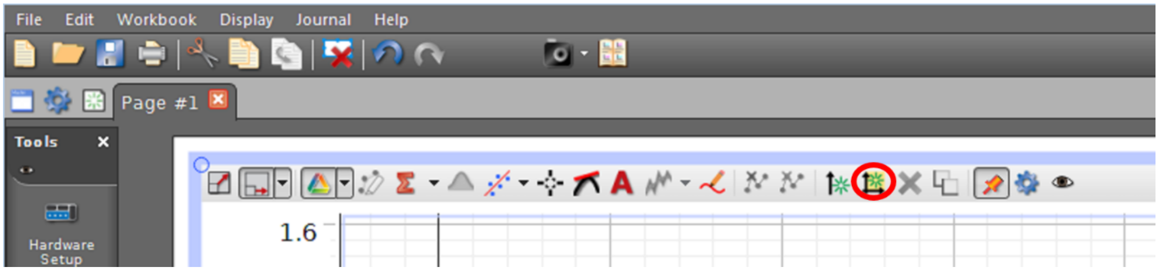

Figure 4: Pasco toolbar. New plot area is circled in red.

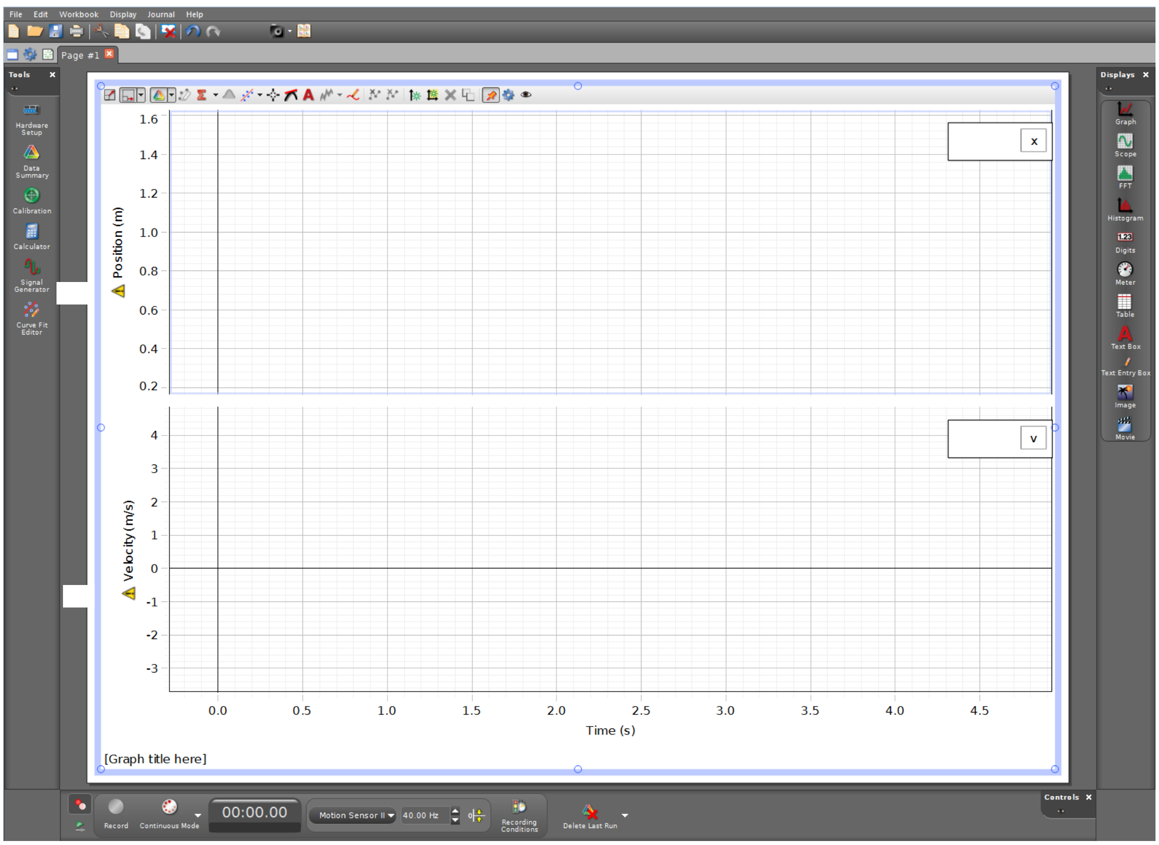

Figure 5: Graph display with two plot areas.

7. Hold the ball about 15 cm below the motion sensor. Click on the red **Record** button at the bottom of the Capstone screen, see Figure 6. Release the ball when the timer begins.

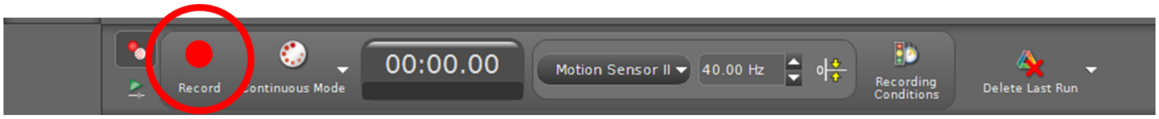

Figure 6: Record button starts taking data.

8. After the ball has bounced as many times as possible, press the **Stop** button in PASCO Capstone. You will need to record a total of 10 bounces but these may be collected from different trials as you will most likely not get 10 usable bounces from one trial.

9. Since the motion sensor is located above the ball, the sensor gives an inverted coordinate system of reference. The position 0 meters is always located at the sensor. The sensor records positive distances as the object moves further away from the sensor, see Figure 7.

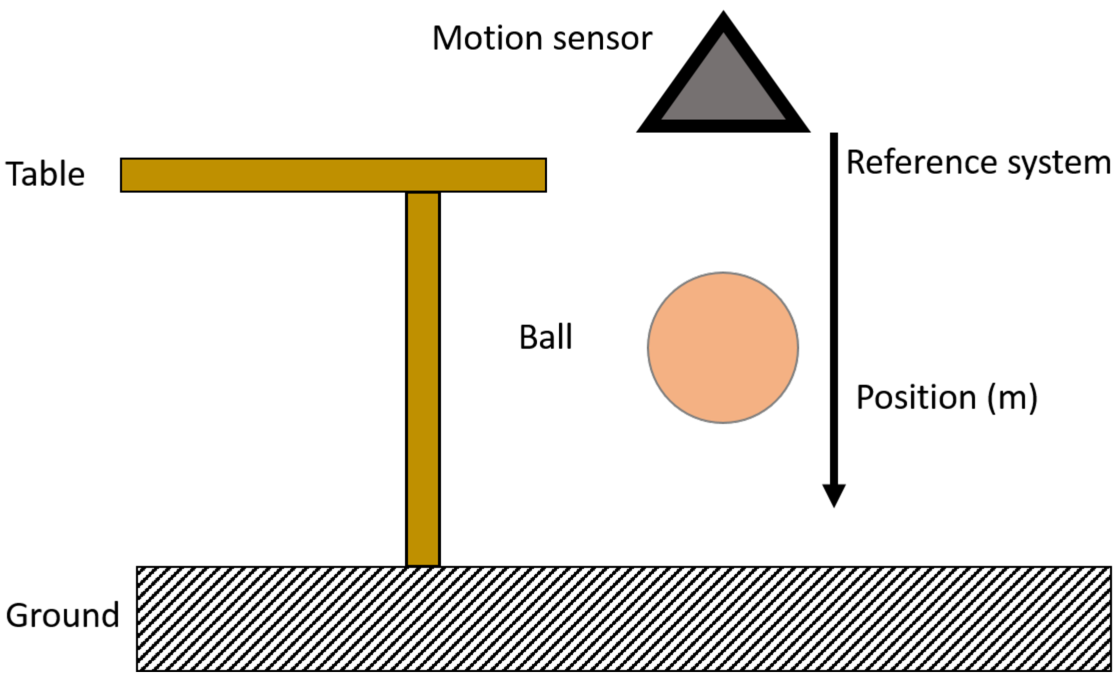

Figure 7: Experiment sketch and reference system.

10. Equation (1) relates position and time for motion in one dimension. You should expect to see a quadratic shape for the position vs time curve for each bounce, see Figure 8.

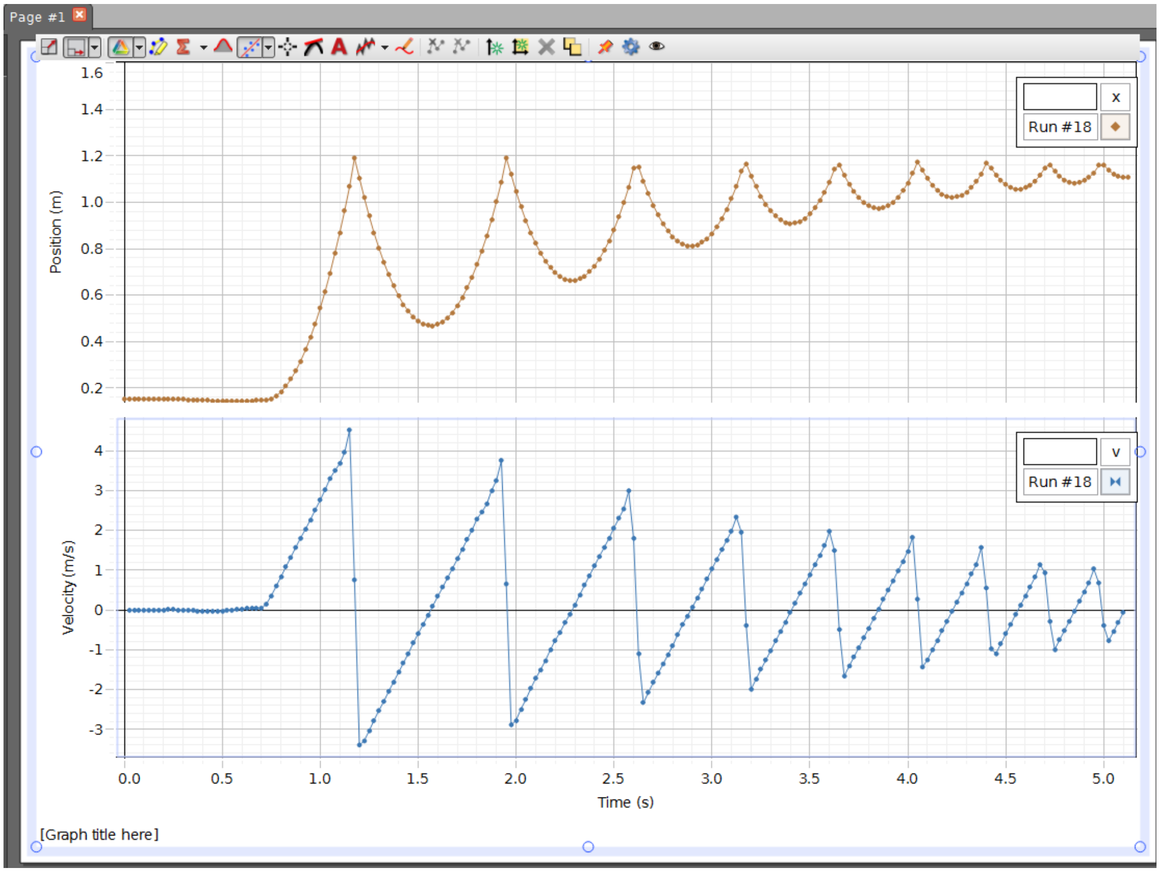

Figure 8: Position vs time and velocity vs time.

11. For the velocity vs. time graph, note that for each section where the ball is in the air (one bounce), this graph is a straight line as predicted by Equation (2), see Figure 8. It should be noted that the acceleration is positive because the location of the motion sensor gives an inverted coordinate system of reference as explained in step 9. Gravity is accelerating the ball away from the motion sensor which gives a positive position.

12. The starting point for each section is the rebound velocity after the bounce. The end of the section is the velocity with which the ball collides with the floor at the next bounce. Click the **Highlight Data** icon to create a rectangle that will select data points, see Figure 9. Move the rectangle and adjust it around the section of your velocity plot where the ball is in the air. The selected data will be highlighted.

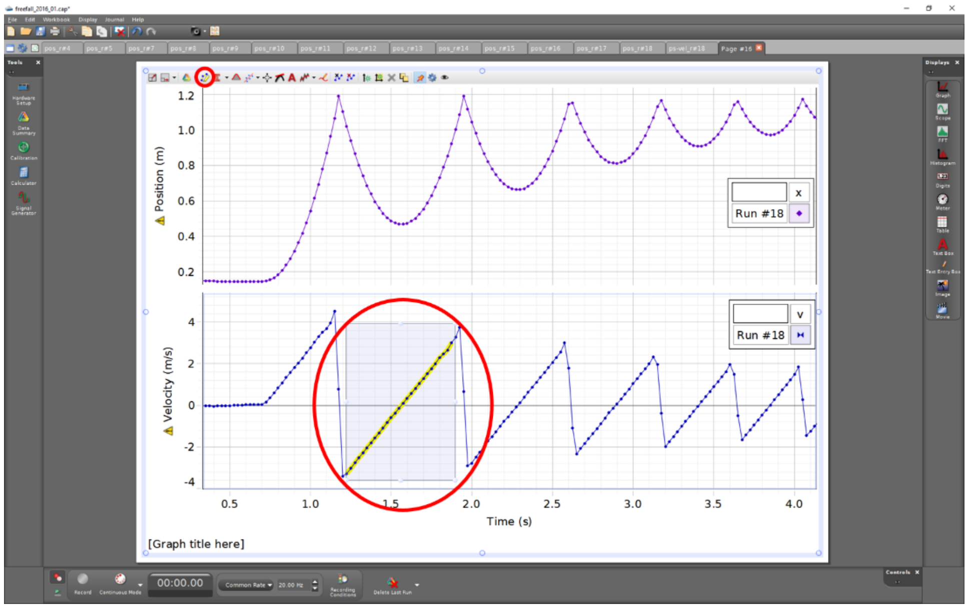

Figure 9: Highlight tool to select data.

13. Click the **Fit** icon on the toolbar above the graph, see Figure 10. Select **Linear Fit** from the drop-down menu to display the slope of the selected region of your velocity vs. time plot. The slope (m) of this section of velocity vs. time plot is the acceleration due to gravity.

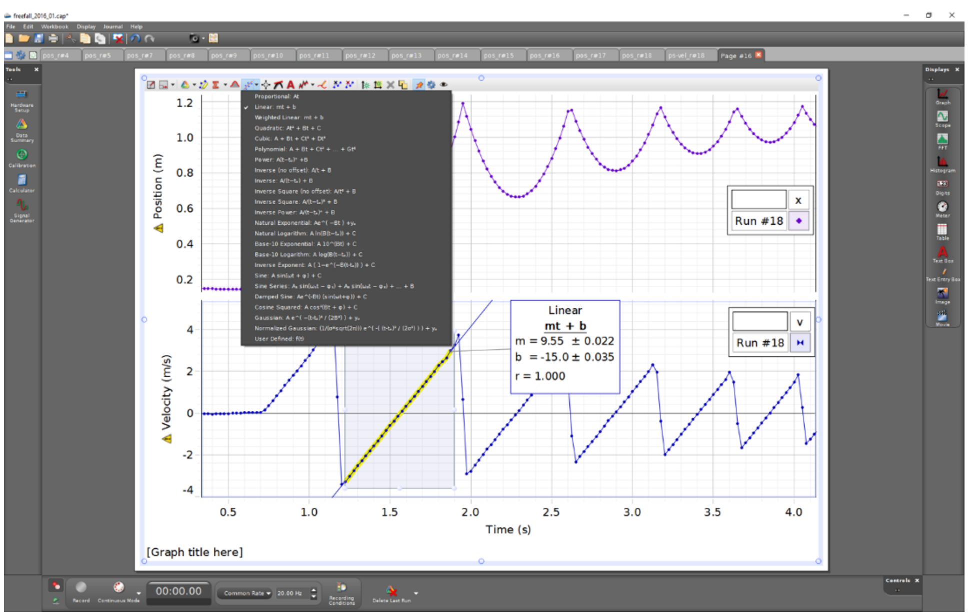

Figure 10: Fitting tool, linear fit.

14. Repeat this process to find the slope of the velocity curve for 10 bounces.

15. Make a table in Excel that documents the 10 slopes.

16. Calculate the average value of g for the 10 bounces you recorded. To do this, select a cell and type '=AVERAGE(A1:A10)' assuming that your g values are in cells A1 through A10. If they are not, type in the appropriate range of cells to calculate the average.

17. Calculate the standard deviation for g, σ_g, by selecting a cell and typing '=STDEV(A1:A10)'. If your data has been placed in a different column, adjust your cell range.

For your Notebook

Make a table and show the results found in step 16 and 17.

In your summary discuss the shape of each graph that you recorded in this lab and what information it contains. Did your average value for g found in step 16 agree with the accepted value within one standard deviation?