George Mason University

Physics for Life Sciences Lab

1-Dimensional Motion and Free Fall

What can we learn about the rate of change of a falling ball?

How can this be related to measurement uncertainty and the standard deviation used in last lab's experiment?

Learning Goals:

- **Students will learn how to work with Capstone data acquisition software and the motion sensor.**
- **Students will analyze repetitive measurements of the acceleration of gravity using the Amoeba Motion Lab as a procedural model analysis of the data.**
- **Students will analyze the position, velocity, and acceleration vs. time graphs to learn where how each graph's shape and phase are related. (Remember phase is a shift of a graph along the x-axis.)**

Materials

Motion sensor, Pasco 850 Universal Interface, basketball, PASCO Capstone software

Reference

Giancoli, Physics, 7th Edition: Chapter 2, sections 3, 4, 5, 7, 8

Background Theory

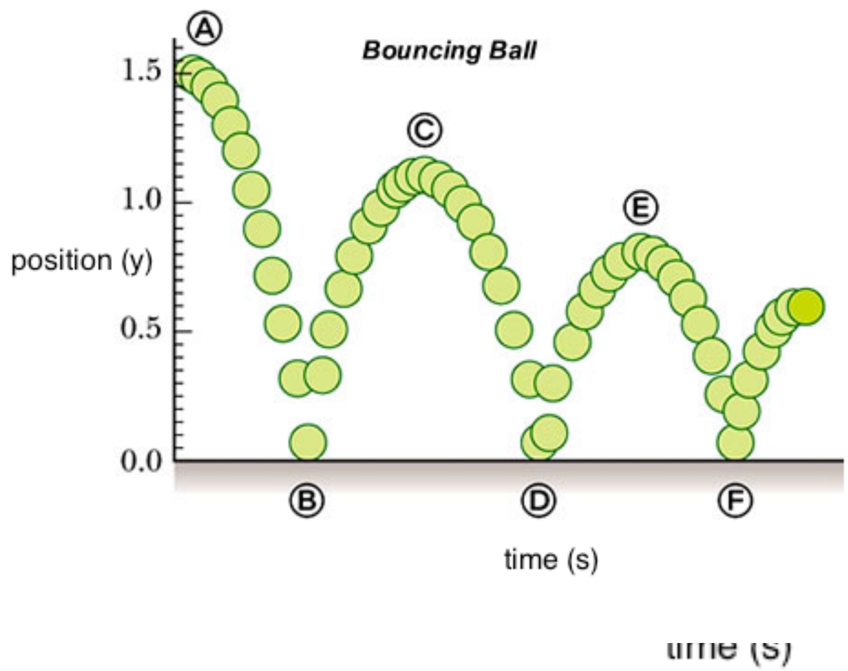
A free falling object accelerates toward the earth with a constant acceleration equal to gravity given the symbol 'g' and equal to $g = 9.81\ m/s^2$. We have experienced this in our everyday life as objects fall, either by design or accident, but gravity also acts on smaller objects. In fact researchers are now discovering that gravitational affects have shaped our evolution with actin scaffolding in large cells to hold up organelles. To read more about gravity limiting cell size, see the supplemental materials link on **Blackboard** in the **Free Fall laboratory folder**.

From lecture you have seen that an equation to model the position of a falling object in 1-dimension is written as:

$$y - y_o = v_o t - \frac{1}{2} g t^2$$

This equation gives vertical position (or height), y, as a function of time, t, where y_o is the initial vertical position, v_o is the initial velocity and g is the acceleration due to gravity.

If we inspect the above equation we find that it is a parabola. A parabola is a function that grows as the square of the independent variable. In this case – t = time is the independent variable and y is the dependent. Therefore, if we graph y vs. t we will see the following shape for a ball repeatedly bouncing.



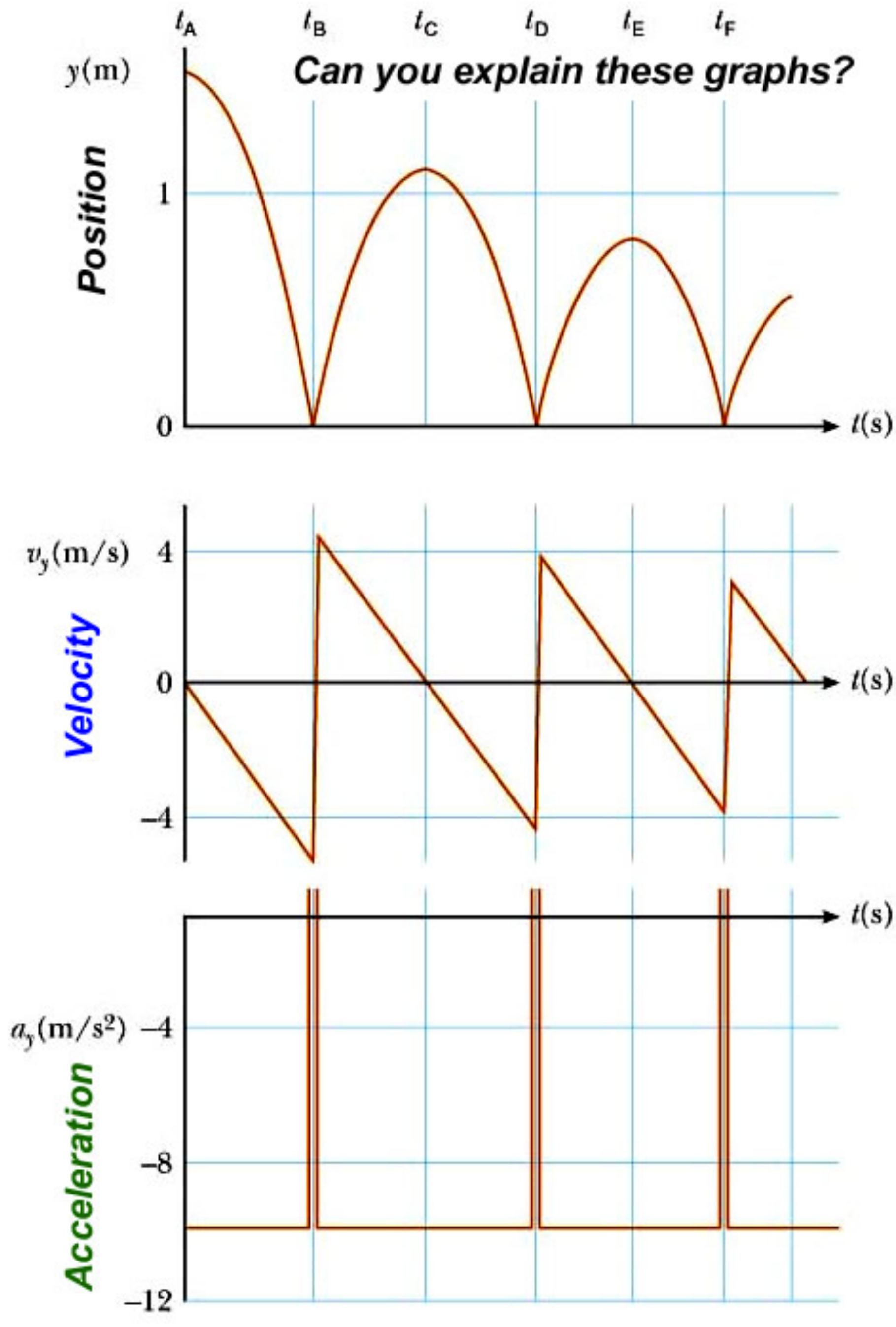
Now, what is the velocity or speed of this motion? To find this we look at the slope of the above graph –

$$slope = velocity = \frac{Rise}{Run}$$

One can see from the above graph that the velocity will not be constant for this motion – but what shape will it have? (Remember velocity is the slope of two adjacent points of the position graph and NOT the average velocity from time = 0s).

It turns out that the shape will be linear with respect to time as seen on the following page. This will always be the case for any motion that graphs a parabola. This is due to calculus and thus is beyond the mathematics required for this course but it is important to note that physicists need only have a model for the motion and can using mathematics also model the motion of velocity and acceleration.

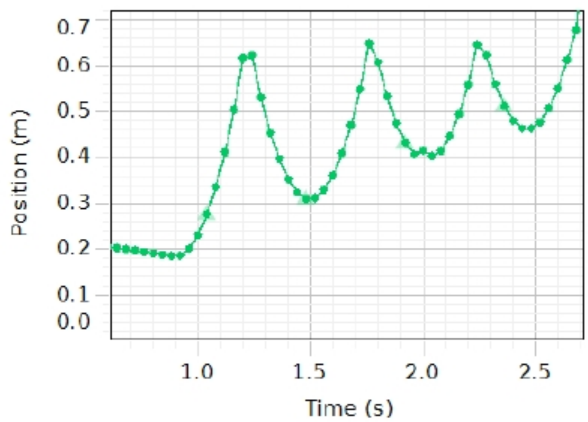
Include in your formal lab report:
Talk in your group and explain WHY the velocity and acceleration graphs appear as they do in the figure below. Make sure to discuss why some values are NEGATIVE or POSITIVE and why there is a discontinuity in the acceleration vs. time graph.

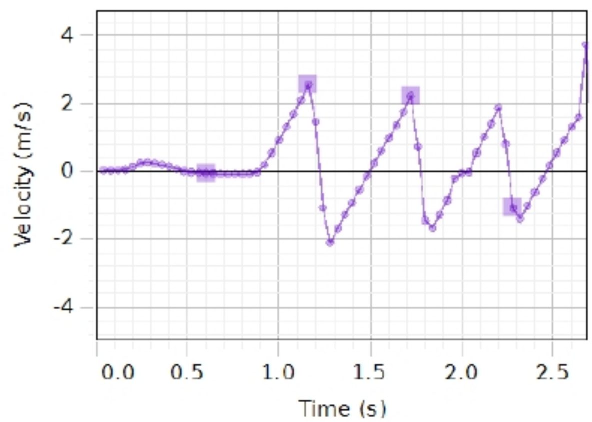


Experimental Procedure

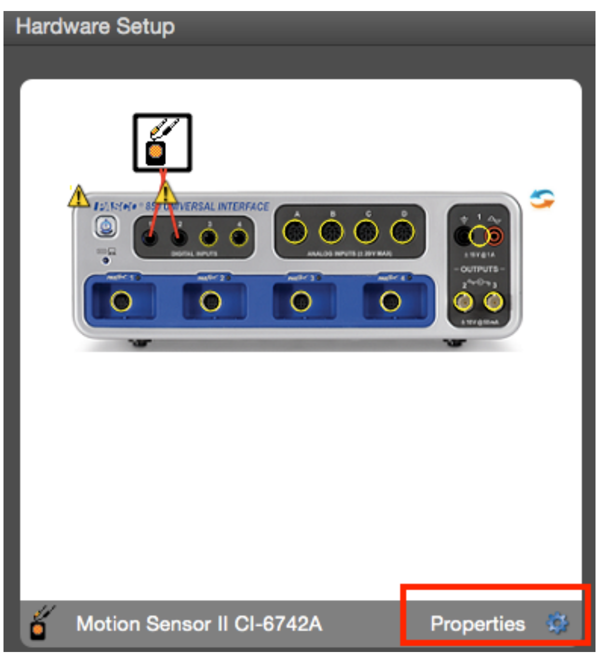
In the experiment we will use a motion sensor (an ultrasonic position sensor) to record several bounces of a ball that is dropped from about 8-15cm below the motion sensor and bounces on the floor. (Note: If the ball is too close to the motion sensor it will record false readings.) The motion sensor is mounted on the edge of the table facing down. Ensure that it is sensor is positioned downward as the sensor sends out a pulse that bounces off the ball and therefore must be able to follow the ball as it falls. If the sensor is angled – this may not happen and you will get spikes in your position data.

Data when collected properly will look like the image above. Notice that the first second of data does





not appear as the theoretical curves in the theory section – this is because this is data before the release of the ball.

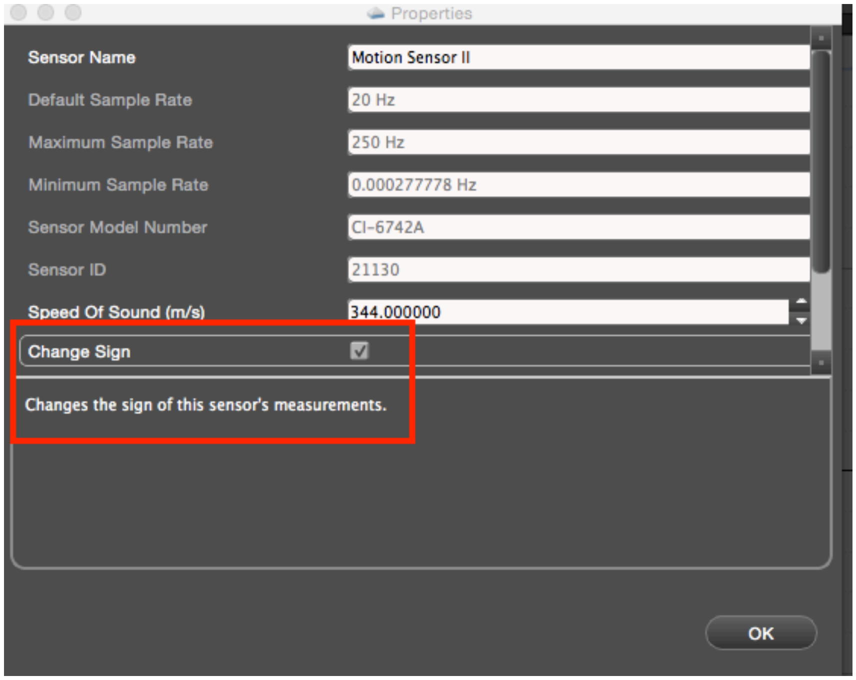


Also notice that the image of the position vs. time graph appears inverted. This is happening because the motion sensor is ABOVE the bouncing ball.

To remedy this inversion Capstone can flip the signs of the position data for you. Choose this option from the Properties for the Motion Sensor in Capstone.

If this is done – the image will appear like the theoretical graph shown on page 3.

Once you select Properties you will see the options shown in the image on the following page. Check the 'Change Sign' box outlined in Red in the image. Then click OK. Your data will now be inverted.



Setting up the equipment:

1. Check to make sure that the motion sensor is set to the correct distance range for today's lab. If the distance is 1m or less you can use the cart image OR if you sensor is mounted high off the floor and the ball falls over a meter – you can use the long distance setting of the stick figure. If you have trouble with sensor set at one type of distance – try the other setting to see if data improves.

2. Plug the yellow and black wires into the 1 and 2 digital inputs, respectively, on the 850 Interface Box. Choose Capstone software and **Hardware Setup**. Select Motion Sensor II from the sensor list on ports 1-2. Here choose properties and invert the position data as discussed above.

3. Change the sample rate of the **Motion Sensor II** to 40 Hz (this option is located at the bottom of the Capstone screen).

4. Select Table & Graph then click on the y-axis label and choose either position or velocity.

5. To create new tables or graphs the icons on the right side of the screen can be dragged on to the workspace.

Taking data and Analyzing Results:

Hold the ball about 8-15 cm below the motion sensor. Click the **Record** button on bottom of the Capstone screen. When the timer begins to show the passage of time, then release the ball.

After the ball has stopped OR the graph is no longer adequately mapping the ball's motion, press the **Stop** button. If possible, try to get a minimum 6 bounces from a single drop.

1. Look for trends in the data and observe these in your conclusions. How do your graphs of

position, velocity, and acceleration compare with the ones provided in the theory section?

2. An important fact to realize is that the motion sensor measured the position of the ball then CALCULATES the velocity (change in position/change in time) and acceleration (change in velocity/change in time) from the pulse time and the change in position between pulses. Therefore – the velocity and acceleration values have more uncertainty than the position since these values depend upon the uncertainty in the change in time AS WELL AS the change in position. Look at the graphs your group produced – do the velocity and acceleration graphs appear to have a larger fluctuation of data than seen in the position vs. time graph? Discuss in your conclusion.

3. Determining the acceleration of gravity can be done in many ways – one of the easiest and most direct is to inspect the velocity vs. time graph. We know that acceleration is how fast the velocity is changing and therefore written as: $a = \frac{\Delta v}{\Delta t}$

Therefore, it is the slope of the velocity graph. We can use Capstone to find the slopes of each section of the velocity graph for each free fall or bounce up. Notice that we want to find the slope for both the falling and the rising motion so that air resistance is negligible. Note that air resistance is always pointing away from the direction of motion but the force of gravity – always points downward. Draw the two free-body diagrams for the motion UP and DOWN and discuss why the experiment includes both motions and not just one or the other.

Now – find the acceleration values:

4. Use the Fit menu button at the top of the graph. Select Linear Fit from the Curve Fit menu to display the slope of the selected region of your velocity vs. time plot. The slope of this part of the velocity vs. time plot is the acceleration due to gravity during the selected region of motion. The uncertainty in slope is also presented.
5. Repeat #4 for at least 10 bounces. These bounces will likely come from more than 1 drop if bouncing is found to be difficult.
6. Make a table in Excel that shows these results for the bounces recorded. Calculate the average value and standard deviation (estimate of uncertainty) of "g" for the bounces recorded in the table in Excel.
7. Inspect the acceleration vs. time graph – find the mean and the standard deviation for the acceleration. How does this value and uncertainty compare to the average value of ‘g’ and its uncertainty from #6.
8. Note that the average value has on average a smaller uncertainty or standard deviation than a single bounce. To determine the uncertainty in the average – statistics states that on average the uncertainty of an averaged value is reduced by $\frac{\sigma_g}{\sqrt{N-1}}$ where N = # of measurements being averaged. For more on this reduction in uncertainty for the average

go to the Measurement Uncertainty document on Blackboard under resources. Notice there is an example of averaging ‘g’ and determining if the data demonstrates consistent data. Use this as a guide in discussing your data results and make sure to include discussion of the following points:

a. Is your data accurate? Is it consistent with theory?
b. How precise was your data (calculate the %uncertainty compared to the average ‘g’ value? Discuss.
c. Do you think your data was dominated by random or systematic uncertainties? Explain reasoning and if possible hypothesize on where this could have arisen in the procedure.

References:

Note: Images found on pages 1-3 are from the following website:
http://sdsu-physics.org/physics180/physics195/Topics/chapter2.html

All other images in this write up were created by image capturing using Pasco Capstone software and Mac’s Grab utility.