PHYS 1P91 Experiment 06

Kinematics 3 : Projectile motion

Notes

- Words in blue are links to additional reading or videos.
- Text in gray boxes are hints and things to take note of.
- Text in red boxes are important instructions or prompts that guide you to DISCUSS some of the key RESULTS and CONCEPTS learned in the lab. These prompts may not be the only items that need to be included in your report.

1 Lab objectives

- Use the iOLab to study projectile motion.
- Show how the distance traveled under constant acceleration increases with the square of the time.
- Show how 2-dimensional motion is independent in perpendicular directions.

2 Introduction

Consider the iOLab in free fall. In Figure 1, we see that the only force acting on it is gravity. Certainly inside the accelerometer sensor the "proof mass" is pulled toward the earth (or at least the axis x, y, or z of the iOLab pointed towards the earth), but so is the rest of the iOLab. In fact, since all parts of the sensor, like the rest of the iOLab, is moving together, the proof mass has *not* shifted with respect to the sensor "fingers". Thus the sensor's electrical capacitance is unchanged, and it should read zero acceleration in the case of free fall. (A figure of what the accelerometer sensor looks like was posted in Lab 04)

We can therefore use the iOLab's accelerometers to determine when it's in free fall, because they should record zero, not g! (See the first paragraph here.)

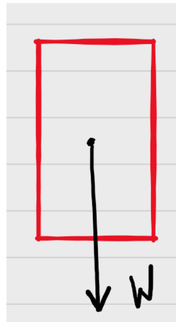

Figure 1: Free body diagram of the iOLab in free fall.

This is interesting, because you could not weigh yourself while in free fall, because you could not push against any scale or sensor. You are all falling together. In spacecraft in orbit, or drop style roller-coasters, you are “weightless” for the time that you are in free fall.

In projectile motion, the horizontal range of the object x is independent of the vertical, or height y motion. We will use the definition of x and y from the textbook.

$$x = x_0 + v_{0x}t \tag{1}$$

$$y = y_0 + v_{0y}t - \frac{1}{2}gt^2 \tag{2}$$

The constant velocity in the horizontal direction is v_{0x}, and since there is no horizontal force, it doesn’t change during flight. Notice that the height of the object decreases with the *square* of the time spent in flight, and does not depend on the horizontal velocity v_{0x} at all. Note these equations are only valid at lower speeds. At higher speeds one would normally account for drag, but for this lab we will ignore it.

Let’s test this theory with the iOLab.

3 Procedure

In this lab, you’ll be dropping the iOLab from different heights. Find some pillows, towels, and other soft things to catch the iOLab. You’ll also need the tape measure and maybe a partner to help spot where it lands.

> I wasn’t brave enough to drop the iOLab more than about 1.5 m myself. I also found out the hard way it can bounce from a more rounded pillow in

unexpected directions. I always used an array of pillows around the target pillow to catch it.

3.1 Prepare the iOLab

For this lab, the `Accelerometer` sensor needs to be calibrated for all three directions.

Connect the iOLab device and open up the Settings menu. Enable a_x =-g, a_y =-g, and a_z =-g. Select the 6-point calibration button and follow all of the steps until you have a green checkmark at the end.

To verify that the calibration worked, take two sets of accelerometer data (2-3 seconds) with the device sitting in each of the positive and negative directions. If the new data in either direction averages to $\pm$g, the calibration was successful. If not, repeat the calibration process. Make sure the table is level and that you do not bump it during calibration.

4 Take data

REMINDER - if you need to *calculate* any uncertainty value(s), you need to include a separate file with your error propagation derivation(s).

4.1 Free fall

4.1.1 Practice

First let's drop the iOLab vertically. Extend the tape measure a little more than 1 m, and secure it vertically against the edge of a table or along a wall, so that the zero end just touches the top of the soft surface that will catch the iOLab. A partner with a steady hand could also hold it. This may need readjusting each drop.

Due to its shape the iOLab can start to tumble around any of its three axis, some more easily than others. Determine the best orientation to drop the iOLab, avoiding it dropping directly on its wheels. Explain in your lab which orientation is best and your rationale.

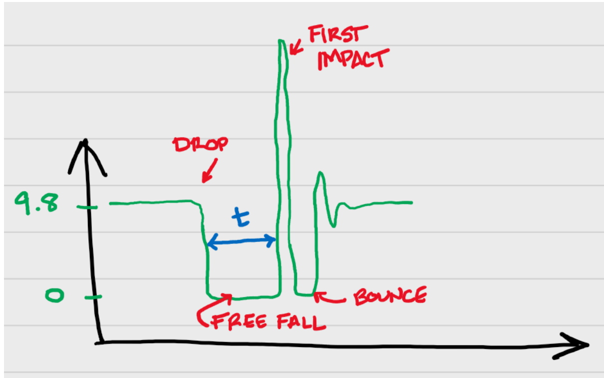

Figure 2: Hypothetical "dropped" iOLab accelerometer data. The sign of the gravitational acceleration depends on which orientation you have it.

> Take a top down picture of your setup as if you were about to drop your iOLab. Make sure it shows the tape measure, iOLab, table and cushion for catching the iOLab.

Practice dropping the iOLab so that it falls straight along one of the axes, without tumbling. Look closely at the accelerometer data; it might look something like Figure 2.

Zoom in to the very brief drop. You should see where the accelerometer briefly stopped measuring g and went to zero. What you want is the time period t of the fall. If you zoom into exactly that region, the statistics should show you the range of x data (which is time) measured in seconds. Alternatively, you could use the cursor and your best guess to find the start and stop times of the fall.

> How did you determine the time of flight, *i.e.* the total time the iOLab was in the air?

4.1.2 Experimental Data Collection

> Pick 9 different drop heights between 10 cm and 100 cm, specify why you selected the heights you did in your lab report.

> Note: make sure you measure consistently, *i.e.* if you use a drop height of 10 cm and measure the height to the bottom part of the iOLab, when you set up the next experiment the height also has to be measured to the bottom of the iOLab. The actual place you measure to on the iOLab does not matter as long as you are consistent!

For your 9 drops record both the drop height and fall time. Estimate the uncertainty of each measurement of height and of time, explain how you determined them in your report. Include two properly labeled acceleration-time graphs, feel free to pick your best two attempts.

IMPORTANT: be careful which direction of the accelerometer data you are looking at. Since the iOLab turns a bit in the air they will all have similar features however the data taken in the direction of the drop will be the easiest to read the data off of. ie. if you drop the iOLab in the z direction on to its back then make sure to look at a_z

Look at equation 2 above. Dropped from rest, the initial velocity $v_{0y} = 0$. Let the initial height be the origin, which means that $y_0 = 0$. Solving for the elapsed time of the fall,

$$t = \sqrt{\frac{2h}{g}}. \tag{3}$$

Let's try to find the value of g from this data and equation.

Reload your session of iOLab online to clear the data field. In the data field, type in the drop data, the x data being the falling distance, and the data for the y axis being the falling time. Don't forget to include the data point 0 m, 0 s. Label your axes - make sure you know what units you are using as they WILL affect your value of g.

Fit the data to the equation above by typing it into the equation box: `sqrt(2/A)*sqrt(x)`, where `A` will be the fitting parameter.

Don't forget you can only have guesses filled in for parameters you are using. If your graph doesn't fit automatically check to make sure that the only guess filled in is A.

Fit the data, and report your value of g with the uncertainty determined by the fit. Include a graph of the fit with axis labels in your report. You should be within 15% of the true value; were you? Were you within experimental error of the true value?

4.2 Projectile motion

True projectile motion, like an artillery shell, would be hard to measure. Even if we could launch the iOLab from a ramp at a particular upward angle, it would be hard to measure how high it reaches before falling. However, if your table is not too high, rolling it straight off the end of the table would mean a launch angle of zero degrees. The wheel sensor can tell us the horizontal velocity of iOLab before it starts to fall, which is v_{0x} from equation 1.

> The iOLab will make one half-tumble when rolled off the table. That's okay because free fall is weightless, *no matter the orientation of the iOLab*.

To see that the horizontal velocity of the iOLab is independent of the drop time, calculate the expected fall time for the height of your table and the correct value of g, using equation 3.

> Record your table height and expected fall time in your report.

> In this next section you will be applying a horizontal velocity to the iOLab by rolling it off a table. This will make the horizontal fall distance longer. Make sure you have enough padding on the ground to catch it. Similarly, there does not need to be a wide variation in speeds you need just enough force to have it roll off the table each time, you are not trying to have it fly across the room!

In the software select both `Accelerometer` and `Wheel` sensors.

IMPORTANT - MEASURING TO THE TABLES EDGE: Gently tie one end of string to the calibration weight. Hold the calibration weight just over the edge of the table, so that the string is on the edge. Make a mark where the string touches (I used tape, it doesn't have to be perfect). Once the calibration weight stops swaying back and forth slowly drop it until it hits the floor. Once it is on the floor you can let the string fall down as well, you don't it on the table where you will be rolling your iOLab. The center of this calibration weight marks the edge of your table. You will use the mark on the table (or the piece of tape) to centre each projectile trial as best you can.

Roll your iOLab off the end of the table as straight as possible (centered with your mark/tape on the table), at different speeds. Try to spot where it initially landed. Now measure the horizontal distance the iOLab by measuring the distance between the initial fall position and the calibration weight.

> **Make sure there is a soft landing spot at the right distance!**

Record the actual fall time of the iOLab for five launch velocities.

Record the distance the iOLab travelled from the table, and estimate its (understandably large) uncertainty.

Describe how you determined the initial horizontal velocity in your lab report.

IMPORTANT: this next question asks you to describe trends in your data. It is your job to determine HOW you want to show these trends. Your goal is to use whatever needed to easily show/convey to the reader how to understand the trend.

Is there a pattern between fall time and horizontal distance travelled? Explain why this might be.

Does rolling it faster off the table change the time of flight? Explain why this might be.

Is there a correlation between launch velocity and horizontal distance travelled? Explain why this might be.

What role does air resistance play in your measured value of g? After all, the iOLab flies like a brick, and is not very aerodynamic.

Describe possible sources of error encountered in this lab.

Finishing Up

Now that you have completed the lab, be sure you filled out all portions of the data tables (templates found on Sakai), include figures, and develop a robust discussion using prompts found throughout the manual.

Ensure to give yourself enough time to complete the report and to hand it in by the due date as late lab reports will not be accepted! If you have any questions please attend a live lab session to get help from one of the course lab demonstrators, or email Phys1P91@brocku.ca.