**PHY 123 Lab 3 - Projectile Motion**

The purpose of this lab is to study projectile motion of an object which is launched horizontally and drops a certain height before it hits the ground.

Important! You need to print out the 1 page worksheet you find by clicking on this link and bring it with you to your lab session. [http://www.ic.sunysb.edu/Class/phy121pk/labs/pdfs/lab3worksheet.pdf]

If you need the .pdf version of these instructions you can get them here [http://www.ic.sunysb.edu/Class/phy122ps/labs/dokuwiki/pdfs/phy123lab3.pdf].

**Video**

**Equipment**

- ramp shaped like a “ski jump” with a horizontal positioning screw
- clip (can be moved) on the inclined ramp for placing the steel ball at reproducible position(s)
- steel ball
- photogate
Introduction

This experiment presents an opportunity to study motion in two dimensions. We investigate projectile motion, which can be described as accelerated motion in the vertical direction ("y") and motion with constant velocity in the horizontal direction ("x"). Review the material in KJF2, Chap. 3.6 and 3.7, especially Example 3.11 on p. 86. An object launched horizontally with a velocity \( v_x \) and dropping a height \( h \), has the following relation between its horizontal distance traveled and \( v_x \):

\[
x = v_x \sqrt{\frac{2h}{g}}
\]

(3.1)
Determine experimentally the relationship between horizontal distance and initial velocity

You will establish the proportionality constant between the horizontal distance, \( x \), and the horizontal component \( v_x \) of the initial velocity (which, by the setup, is in the x-direction) by studying the motion of a steel ball launched from a ramp. Because there is no acceleration of the ball in the x-direction (if we ignore air friction and rolling friction on the ramp), the horizontal component of the velocity of the ball (measured using the photogate) remains constant until the ball hits the floor. The following are the important steps in getting the experiment underway.

- Measure the height, \( h \), the vertical distance from the bottom of the ball (when it's stationary at the end of the ramp) down to the floor and record it on your worksheet. Use the “poor man’s plumb bob” (string with paper clip attached) to find the point on the floor that is vertically directly below the point where the plumb-bob string touches the pulley tangentially. Assume that \( h \) has an absolute error of 2 mm.

- Measure the “effective diameter” \( d_{\text{eff}} \) of the steel ball. “Effective” refers to the diameter actually “seen” by the photogate. The measurement of \( d_{\text{eff}} \) may be accomplished by using the rotary-screw device to move the photogate from the front to the back of the steel ball (kept stationary) on the launching ramp. Make sure your platform with the ramp is solidly clamped to the lab bench when you turn the wheel that turns the screw to displace the photogate. The effective “front” and “back” of the ball are found, respectively, when the photogate is blocked or unblocked as seen by the LED (light emitting diode) on top of the photogate. The LED is brightest when the gate is blocked and dimmest when the gate is unblocked. You read the displacement on the length scale attached to the platform. Record your measurement on your worksheet and assume the absolute error for the diameter of the ball to be 1 mm. Note that once you have measured the value of \( d_{\text{eff}} \) for your setup, DO NOT change the position of the photogate. Shifting the photogate will change \( d_{\text{eff}} \).

- Drop the steel ball from the lowest mark on the inclined ramp and note approximately where it lands on the floor. Then repeat this for the ball being dropped from highest mark on the inclined ramp. Tape the carbon paper with a piece of white paper underneath it to the floor so that the ball will hit the paper no matter where it is launched on the ramp.

- Now connect the photogate output to the interface box by plugging its cable into the top socket (labeled “DIG/SONIC 1”) of the black interface box (“LabPro”). Test the photogate: block the photogate beam with your finger and see the red light on the cross bar of the photogate turn on (or, at least, get much brighter).
Turn on the computer and check the system; double click the icon "Exp3_t1_t2". A window with a spreadsheet on the left (having a “Time” column) comes up. On top is a window called “Sensor Confirmation”. It should show the following kind of information (though it may be displayed a bit differently):

<table>
<thead>
<tr>
<th>Sensor Specified In File:</th>
<th>Sensor To Set Up:</th>
<th>Where:</th>
<th>Use:</th>
</tr>
</thead>
<tbody>
<tr>
<td>✔Photogate</td>
<td>Photogate</td>
<td>DIG1 on LabPro</td>
<td>✓</td>
</tr>
</tbody>
</table>

[If you don’t see the above information, do the following: Click Experiment→Set Up Sensors→Show All Interfaces→DIG/SONIC1: you can check the photogate by blocking it and seeing "Unblocked’ go to "Blocked". Click “Close”.

- Click OK.
- Click Experiment→Start Collection.
- Move the clip to a position that will allow the ball to be placed reproducibly at the position of the lowest mark on the ramp. When you place the ball there and then release it (with the computer prepared as above to collect data), the computer will record the time $t_1$ when the ball enters the light beam of the photogate and the time $t_2$ when the ball leaves the light beam of the photogate. The difference $t_2-t_1$ is the time the effective diameter $d_{eff}$ of the ball, which you already measured, takes to traverse the beam of the photogate. You measure the horizontal distance $x$ for the projectile motion of the ball in the following way: you hang the plumb bob from the end of the ramp and measure the distance between the point where the plumb bob touches the floor and the mark the steel ball landing on the carbon paper makes on the white paper.

**Warning:** Do not shift the position of the paper on the floor until you are finished with all your measurements. That paper must remain in the same position.

- When you change the “launch position” of the ball, you will be changing the velocity of the ball through the photogate. Each time the ball passes through the photogate, the time pair $t_1,t_2$ appears on the screen and you record the difference $(t_2-t_1)$ in the table on your worksheet. These time differences allow you to measure the initial of the velocity of the ball for each launch. For each position mark on the ramp, drop the steel ball 3 times and record the difference $(t_2-t_1)$ and the distance measurement. For each position mark, be careful to position the steel ball reproducibly at the same launch location on the ramp. (Since there are 5 position marks on the ramp, you should have a total of 15 time measurements and 15 distance measurements).

A tool is provided to help you make some calculations from the data in your table. For each mark on the ramp you Eq. (E.5) from the Lab 1 manual is used to calculate the average of the values of $t$ and $x$; enter them into Table 2. **Warning:** You should enter all distance in meters, not cm. Eq. (E.5b) from the Lab 1 manual is used to calculate the uncertainty for the average $t$ and $x$. To calculate the horizontal velocity, the formula $v_x = \frac{d_{eff}}{t_{avg}}$ is used, and to calculate the uncertainty for $v_x$, Eq (E.7) from the Lab 1 manual is used.

You actually don’t need to do all these calculations. Just enter your recorded values below, click submit, and the calculation tool with provide the desired values on a new window tab.

$d_{eff} = \boxed{\text{m}} +/- \boxed{\text{m}}$
From lowest point on ramp
\[ t_1 = \quad \text{s} \quad x_1 = \quad \text{m} \]
\[ t_2 = \quad \text{s} \quad x_2 = \quad \text{m} \]
\[ t_3 = \quad \text{s} \quad x_3 = \quad \text{m} \]

From 2nd lowest point on ramp
\[ t_1 = \quad \text{s} \quad x_1 = \quad \text{m} \]
\[ t_2 = \quad \text{s} \quad x_2 = \quad \text{m} \]
\[ t_3 = \quad \text{s} \quad x_3 = \quad \text{m} \]

From 3rd lowest point on ramp
\[ t_1 = \quad \text{s} \quad x_1 = \quad \text{m} \]
\[ t_2 = \quad \text{s} \quad x_2 = \quad \text{m} \]
\[ t_3 = \quad \text{s} \quad x_3 = \quad \text{m} \]

From 4th lowest point on ramp
\[ t_1 = \quad \text{s} \quad x_1 = \quad \text{m} \]
\[ t_2 = \quad \text{s} \quad x_2 = \quad \text{m} \]
\[ t_3 = \quad \text{s} \quad x_3 = \quad \text{m} \]

From highest point on ramp
\[ t_1 = \quad \text{s} \quad x_1 = \quad \text{m} \]
\[ t_2 = \quad \text{s} \quad x_2 = \quad \text{m} \]
\[ t_3 = \quad \text{s} \quad x_3 = \quad \text{m} \]

Copy the values the computer gives you into the second table on your worksheet. Once you have put your values there you need to make a plot of \(x_{avg}\) on the vertical axis \((y_1, y_2, y_3, y_4, y_5)\) versus \(v_x\) on the horizontal axis \((x_1, x_2, x_3, x_4, x_5)\) using the plotting tool below. Should you include the point \((0,0)\) in your fit (making it a “constrained fit” in the language of the Lab 1 manual) this time? Hint: Ask yourself what is the distance traveled in the \(x\) direction if the horizontal velocity is zero.

x axis label (include units): ____________________________
y axis label (include units): ____________________________

Check this box if the fit should go through \((0,0)\). [ ]
(Do not include \((0,0)\) in your list of points below, it will mess up the fit.)

What kind of errors are you entering below? [None]__________________________

\[ x_1: \quad \text{+/-} \quad y_1: \quad \text{+/-} \]
\[ x_2: \quad \text{+/-} \quad y_2: \quad \text{+/-} \]
\[ x_3: \quad \text{+/-} \quad y_3: \quad \text{+/-} \]
\[ x_4: \quad \text{+/-} \quad y_4: \quad \text{+/-} \]
\[ x_5: \quad \text{+/-} \quad y_5: \quad \text{+/-} \]

Submit
Now you need to calculate the value of the acceleration due to gravity from the slope of your graph. That slope, which we shall call $k$, is related to $g$ through Eq. (3.1) of this Lab 3 manual, viz., \( k = \sqrt{\frac{2h}{g}} \). We can rewrite this equation as

\[
g = \frac{2h}{k^2}
\]

(3.2)

Now you need to calculate what the value of $g$ should be from the value of $k$ you obtained from the slope of your graph and from the value of $h$ you measured earlier. Be careful: If you measured your value of $h$ in centimeters, you must convert it to meters so that your value for $g$ has units of m/s$^2$.

Your final task is to estimate the uncertainty in your measured value of $g$. Both $h$ and $k$ have a certain degree of uncertainty and, strictly speaking, you should take both into account in your estimation of the uncertainty in $g$. You can find the relative uncertainty in $g$ from the relative relative in $h$ and $k^2$ using Eq. (E.7) from the Lab 1 manual. The relative uncertainty in $k^2$ is obtained from the relative uncertainty in $k$ using Eq. (E.8) from the Lab 1 manual. You can then arrive at an expression for the uncertainty in $g$:

\[
\Delta g = g\sqrt{\left(\frac{2\Delta k}{k}\right)^2 + \left(\frac{\Delta h}{h}\right)^2}
\]

(3.3)

Sometimes, when we combine relative uncertainties like this, we can neglect one of them if it is much smaller than the other. Below there is a tool that calculates the uncertainty in $g$ using both the uncertainties in $h$ and $k$, just the uncertainty in $k$, or just the uncertainty in $h$. Enter your values (including your measured value for $g$, not the known, “accepted” value) and click submit. The computer will display the three uncertainty estimates. Based on these three values can you conclude what is the most significant source of error in the experiment? Can you think of ways you could reduce this error?

\[
\begin{align*}
    h &= \text{ } \text{ } \shortrightarrow \text{ } \text{ } \text{ } +/\text{- } \text{ } \text{ } \text{ } \text{ } \text{ } m \\
    k &= \text{ } \text{ } \shortrightarrow \text{ } \text{ } \text{ } +/\text{- } \text{ } \text{ } \text{ } \text{ } \text{ } s \\
    g &= \text{ } \text{ } \text{ } m/s^2
\end{align*}
\]

submit

Finally, you should check whether your measured value of $g$ is consistent with the known, accepted value of 9.81 m/s$^2$.

When have completed all these tasks, you are ready to discuss your results and conclusions with your TAs.