Lab 3 - Projectile Motion
Scientific Data Collection and Analysis (with some experimental design)

Purpose:

This Minilab is designed help you apply the skills you learned in the homework; that is, to collect data with errors, make calculations with error, and decide whether your experiments are valid or not. We will do this by calculating a muzzle velocity (or initial velocity) for a steel ball projectile launcher using two different methods, then calculating the gravitational constant (g) from these velocities. The concepts in this Minilab will follow you for the rest of this lab course, as well as any research you will do on your own in school or in your career.

Apparatus List:

- Steel ball launcher with photogate attachment
- 16 mm steel balls
- Something to stop the ball with (book, wall, etc)
- Table stand with O-ring attachment
- Capstone & Microsoft Excel
- Goggles (highly recommended)

Introduction:

One of the first things you learned in your physics course was kinematics, which is the study of how objects move. You also learned that the first step is to separate the motion into x- and y- components, as is shown in Figure 1. Recall the equation of motion in one dimension with constant acceleration is:

$$x = x_0 + v_{ox}t + \frac{1}{2}at^2 \quad (Equation \ 1)$$

To keep with the convention followed by most physics textbooks, we will keep the horizontal direction as x, and the vertical direction as y. Thus, we define v_{ox} as the x component of the initial velocity, and v_{oy} as the y component of the initial velocity v_0. Assuming there is no air resistance, there is no acceleration in the x direction, so a_x = 0. Also, the ball starts at x_0 = 0. Thus, Equation 1 simplifies to:

$$x = v_{ox}t \quad \quad (Equation \ 2)$$

Now, for the y direction, we see the only acceleration is gravity, g = 9.8 m/sec^2. Considering down towards the floor to be negative, our y equation becomes:

$$y = y_0 + v_{oy}t - \frac{1}{2}gt^2 \quad (Equation \ 3)$$

With this initial information (which should be reviewed!), you are prepared to calculate the velocity using a series of different measurements.
Procedure:

**Warning!**
The mini-launchers used in the following activity can be DANGEROUS if used inappropriately. When at a table with a mini-launcher, you must wear protective eyewear! Do not aim launcher at computers, windows, lab partners or rival lab groups. At the instructor’s discretion, you will be given a “zero” for this activity if your lab group misuses the mini-launcher.

**Activity 1 – Calculating \( v_0 \) using the Kinematic Equations**

As you begin to experiment with the steel ball launcher and a meter stick, you should find it is easy to measure angles (on the side of the projectile launcher) and distance (via the meter stick). It is much more difficult to measure a value for \( v_0 \) using just these devices; however, you can derive an equation for \( v_0 \) using just distances and angles. Using Equations 2 and 3 above, you found the following equation in your homework:

\[
v_0 = \sqrt{\frac{g x^2}{2 \cos^2(\theta) \left[ y_0 - y + x \tan(\theta) \right]}}
\]

You can see from the equation that you need to measure \( x, y, y_0 \) and \( \theta \) to find \( v_0 \). You also learned in the homework that you need the uncertainties of \( x, y_0 \) and \( \theta \) in order to calculate the uncertainty of \( v_0 \). (Remember to use fractional uncertainty as described in the homework!)

To record these data, set the launcher angle around 30°, and push the ball in the launcher until you hear it “click” twice. Launch the steel ball at least five times, and record the distance from your launcher where it lands in the table below. The simplest way to do this is to tape a piece of paper to the floor, and position it so the ball makes a dent in the paper. Then, measure the distance from the table to the center of the dents. Record your measurements below, including errors. Then on the next page, show how to calculate \( v_0 \) and its uncertainty. **Work as a group to do your calculations. When you are finished, recycle your paper!**

**Fill in the tables below.** [3 pts total, .5 pts for measurements, .5 pts per uncertainty]

<table>
<thead>
<tr>
<th></th>
<th>Launch 1</th>
<th>Launch 2</th>
<th>Launch 3</th>
<th>Launch 4</th>
<th>Launch 5</th>
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</thead>
<tbody>
<tr>
<td>( X_{\text{Measured}} )</td>
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<td>( y_0 ) =</td>
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<td>( X_{\text{Average}} = \pm )</td>
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</tbody>
</table>

**Uncertainty Help:**

- After calculating your average value for \( x \), estimate your error using your highest and lowest recorded values. For example, if you obtained a low value of 206 cm and a high value of 209 cm with an average of 207 cm, you would write down \( x = 207 \pm 2 \) cm.
- For \( y_0 \) and \( \theta \), your uncertainty is determined by how accurately you can measure these values. So, if you think you are only accurate to 1 cm with your meter stick measuring the \( y \) value, report the uncertainty as \( \pm 1 \) cm.
- To find the uncertainty for \( v_0 \), estimate the uncertainty by taking your least accurate value (note this may not be the one with the largest error value!), and plug in the upper and lower values of its error range to see how \( v_0 \) changes. So, if you think the value \( y_0 = 15 \pm 3 \) cm is your greatest source of error, solve your equation for \( y_0 = 12 \) cm and \( y_0 = 18 \) cm, then see how much these values vary to determine an approximate error range.
Activity 2 – Measuring $v_o$ Directly

Now, like in your homework, we will want to compare our calculated values of $v_o$ with a directly determined value. To do this, we will use the photogate attached to your ball launcher. The photogate should be plugged into port 1 of the 750 interface. Open the Capstone activity “Projectile Motion.cap”. Select the tab called “Testing the Photogate”. This tab opens a test page that helps you learn about the photogate. Once you understand how the photogate works, go to the next tab called “Photogate Timing of Metal Ball” and read the instructions on how to measure time with the photogate.

Your photogate contains a small beam of light that shines on a detector inside its plastic casing. Capstone records how long the light beam was blocked based on electrical signals received from the photogate. You can test how accurate the photogate is by using a pencil or pen to block the beam (which is blocked when a red light on the photogate lights up), and seeing the width calculated by the photogate. In this experiment, you can find $v_o$ and its uncertainty by knowing the width of your steel ball and the time that the ball blocks the photogate. To find the uncertainty, you will want to know that your main uncertainty will likely not be the ability of the photogate to accurately measure time. (Hint: In fact, a large source of uncertainty will likely be in measuring the width of the steel ball. Why do you think that is?)

Final Result: $v_o = \underline{\underline{\text{_________}}} \pm \underline{\underline{\text{_________}}}$
**Mathematically Calculating Velocity** [1 pt]
Launching the ball at the same angle you used earlier in the Minilab, use the “Time in Gate” measured by Capstone to determine the velocity of the ball and its uncertainty. You may launch the ball several times, but all of the launches should give you the same result. As always, include uncertainty in your calculations, which you may have to estimate. Discuss with your lab group where the greatest uncertainty occurs, and consider this in your calculations. Show all of your work below.

**Using Capstone to Calculate Velocity Automatically** [1 pt]
Capstone can automatically calculate the initial velocity of the ball as it leaves the launcher. Turn to the tab “Timing and Velocity of Metal Ball” of the Capstone activity, where you will see two displays- one for the time the photogate was blocked, and one for the calculated velocity. Note that the velocity calculation assumes your ball is 16 mm in diameter, so be careful about accepting this calculated velocity. Does this match the diameter of your ball? Record the information from Capstone below and then answer Questions 1 through 3.

**Q.1** [1 pt] Compare your values of $v_0$ from Activity 1 and both from Activity 2. Can you claim that they agree? (Refer to the homework if you can’t remember how to do this.) If they do not agree, explain why in 1-2 sentences.

**Q.2** [1 pt] Why is it important to show the uncertainty in each measurement? If you had not considered uncertainty at all, could your calculations have agreed? Why or why not?
Activity 3: Introduction to Data Analysis

Exit Capstone, and open an Excel Spreadsheet. Excel, has data fields that allow you to enter data.

Figure 1 (O-Ring Setup)

In this part of the lab, we will plot the positions (x and y coordinates) of the steel ball. Label two adjacent fields in Excel with “x” and “y”. Underneath “x” and “y” you will enter the measured values. Make sure your ball launcher is level with the horizontal (at 0°), and make sure the ball clicks two times, like the earlier experiment. With your meter stick and the O-Ring apparatus (as pictured in Figure 2 on the left), you will be able to record x and y values. The O-Ring stand can be moved around the floor, and the clamp that holds the O-Ring can move up and down on the metal stand. You will move the O-ring stand to at least 5 different positions on the floor where the projectile goes through the center of the ring, where you can then measure the x (distance from the table) and the y (distance the center of the ring is above the ground) values at those points.
As soon as you have entered all x- and corresponding y-values you need to graph y versus x in Excel in a “Scatter-plot”.

*(Short hint: In Excel select all x and y data by clicking and dragging. Then click on “Insert” -> “Scatter” and select the scatter plot with only Markers.) Please refer to the Excel Tutorial at the beginning of this manual on how to do this if you are not familiar with this Excel feature.

The points should look like a path similar to that of the projectile. (Check your work if this is not the case). You will also need to show uncertainty on your graph in the form of error bars. Again, adding error bars is described in the Excel Tutorial.

*(Short Hint: Left-click once on any of the data points in the graph to select them all. Then click on “Layout” underneath the “Chart Tools”. Towards the right side you will see “Error bars”. Click on “Error bars” and select “More error bars options”. There you can enter a fixed error for horizontal/vertical errors. To switch between horizontal and vertical error, you can select x-Error bars or y-Error bars in the upper left region of your spreadsheet.)*

On the next page, write the equation of motion for y in terms of the x position using Equations 2 and 3, similar to what you did in Activity 1. Note that your equations will be much easier to use than they were on your homework assignment because the angle from which the projectile is being launched is 0°, which should cause parts of your equation to cancel out. Show your work for the derivation of y(x):

**Show your work below.** [4 pts total]
You should now have an equation of the form \( y = mx^2 + b \), where \( m \) is some group of values that is known. This implies that if we plot \( y \) vs. \( x^2 \), we should see a straight line (or, in other words, see a linear fit). To create this graph in Excel, insert a new column between the \( x \) and \( y \) column (Click on the top column letter of the column in which your \( y \)-data are. Then go to the “Insert Cells” button and select “Insert Sheet Columns”). Add a label called “\( x^2 \)” and calculate \( x^2 \) in that column from the \( x \)-data to its left. (Hint: This can be done easily and efficiently with the spreadsheet with minimal effort. Look at the Excel Tutorial if you do not know how to do that or have someone show you.)

You will now plot \( y \) versus \( x^2 \) by selecting the \( y \) and \( x^2 \) data and inserting another scatter-plot.

Now, your last task will be to determine the slope, which will give you a value that allows you to calculate the gravitational constant \( g \). Excel can determine the slope of a graph using the “trendline” (linear fit) – see the Excel tutorial on how to do that if you do not know.

You will also need to find a way to estimate the uncertainty in the slope of this graph (Hint: Look at the scatter of your data and estimate by how much the slope of the trendline could vary and still reasonably fit our data. Alternatively, you can get a the uncertainty in the slope from Excel using the “Linest(…)” command. The exact procedure is described in the Excel tutorial.). Use the obtained slope and its uncertainty to calculate the gravitational constant \( g \) with uncertainty. Show your work in the space given to you below, then answer Questions 3 and 4 on the next page.

**From the slope, calculate a value for \( g \), the acceleration of gravity.** Show your work below, including uncertainty! [3 pts. total]
Q.3 [1 pt] Does your calculated $g$ match the known value of 9.8 m/s$^2$? If not, explain why in 1-2 sentences.

Q.4 [1 pt] Does your calculated $g$ match the known value of 9.8 m/sec$^2$? If not, explain why in 1-2 sentences.