Purpose of the Experiment:
In this experiment you will study projectile motion and use the theoretical equations to make a prediction of range which you will then test.

Setting Up the Apparatus:
A checklist of steps to follow is included at the end of this document. Each group will be given a printed copy of this list during class.

The apparatus has a hollow plastic tube that can be used as a “gun” to launch the projectile, a 12 mm diameter steel ball bearing. The angle of the tube can be changed in 15° increments (determined by threaded inserts in the backboard) and the apparatus can be oriented so the initial vertical component of the projectile’s velocity is either upward or downward. If upward, a spring gun imparts the initial velocity; if downward, the initial velocity is determined by gravity. The photo below at the right shows how to position the apparatus for a downward launch. Note that you simply drop the ball into the open end of the tube. For an upward launch, the apparatus is positioned as in the photo to the left. In either case, the apparatus should be clamped to the table. At the output of the launching tube, the ball interrupts the beam of light from an LED to a phototransistor to produce a signal as it leaves the tube. Terminals connect to a power supply and to the output of the phototransistor, the latter go to input channel A on the SW750 interface.
Predicting the range:
Here is how you should analyze your measurements to find the Range, \( R \). The total time of flight is \( T \) and \( V_0 \) is the initial speed. For an initial velocity pointing \textit{upward} at an angle \( \theta \) above the horizontal, and an initial position of \( X = 0 \) and \( Y = H \), the equations for X and Y motion as a function of time are:

\[
X = V_0 \cos(\theta) t \\
Y = H + V_0 \sin(\theta) t - \frac{1}{2} g t^2
\]

The ball hits the floor when \( Y = 0 \) and we define that horizontal position as the range \( X = R \). The only unknown in the Y equation is the total time of flight, let’s call it \( T \), for which you have a quadratic equation. The solution is:

\[
T = \frac{V_0 \sin(\theta) + \sqrt{(V_0 \sin(\theta))^2 + 2gH}}{g}
\]

Actually, this is only one of the two solutions to the equation. One of the report questions asks you about the other solution. You will also need the formula for the range of a \textit{downward} shot. Another of the report questions asks you about that. Then the range \( R \) of the ball is:

\[
R = V_0 \cos(\theta) T
\]

To save you some of the work, the program calculates \( V_0 \cos(\theta) \) and \( V_0 \sin(\theta) \).

At the output end of the launch tube is a piece of white plastic that contains the LED and phototransistor; there is a small hole about 1 mm diameter where the light beam crosses the tube (see the pointing finger in the photo at the right). For the height measurement, determine as accurately as you can the vertical distance from this hole to the floor. To help with this measurement, your apparatus has horizontal yellow lines (see arrow at top left on the upward photo and lower left on the downward photo).

Later you will measure the horizontal distance from the light beam to the impact point of the ball, i.e. the range of the projectile. For this second measurement, you will use a plumb-bob and string to find the point on the floor directly below the hole. To help with this second measurement, your apparatus has vertical yellow lines to align the plumb-bob string (see arrow at lower left on the upward photo and lower right on the downward photo).

Place a piece of white paper on the clipboard and cover it with a piece of carbon paper with the carbon side down. The impact will make a mark on the white paper that allows you to determine where the ball landed.

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{image.png}
\caption{Photo of the apparatus with the light beam and plumb-bob.}
\end{figure}

Making the Measurements
Start the LabVIEW program \textit{ProjectileMotion.exe}. The program is controlled by the main pull-down menu at the left above the graph. The program will measure the input voltage on channel A of the SW750. This voltage is normally close to zero, but the phototransistor voltage rises to about 6 V when the light beam is blocked by the ball bearing. The voltage will be measured every 200 \( \mu s \).
To make a measurement, choose the Measure option from the menu. The RUN button will change to bright green, indicating the program is ready. When you are ready to launch the projectile, click the RUN button and then launch the ball bearing. After the window time has passed, the RUN/STOP button should change from red back to green and you should have a graph like the one shown below except that the peak will not fill the whole graph.

![Graph](image)

The next step is to use the cursor to determine the time the ball bearing took to cross the light beam. This will be used to calculate its initial velocity.

Make sure the left (cursor) button on the graph control palette is selected. This lets you click on and move the vertical red dotted line back and forth. The cursor will change to vertical lines with arrows when you are close enough to the red line to grab it. Press and hold the left mouse button to move the red line.

The leading edge of the ball is half way across the light beam when the voltage pulse has risen to half its maximum value, and the trailing edge of the ball is half way across the light beam when the pulse has fallen to half its maximum value. Thus the launch speed of the ball is 

\[ V_0 = \frac{D}{\tau}, \]

where \( D \) is the ball diameter and \( \tau \) is the full width at half maximum of the phototransistor output pulse.

Select the cursor button on the palette. Position the red line on the data point that is closest to half way up the rising edge of the pulse and click the green RISE button in the box labeled “Select Time of...”; that tells the computer the time that the leading edge of the ball was half way across the light beam. Move the red line to the falling edge of the pulse and repeat the process, but click the green FALL button. (The cursor stops only on actual data points, so you may not be able to position it exactly half way up or down the pulse.) If you chose a point slightly more than half way up for the rise, then pick one slightly more than half way down for the fall, or vice versa. That should reduce the error in determining \( V_0 \). The computer subtracts these two times to get \( \tau \). Now you are ready to complete the data analysis. Click the Results tab. The Rise and Fall times should be displayed to the right of the bottom visible row of the table. Type the launch angle (in degrees) into the Input Parameters table. Choose Analyze Data from the pull-down menu, and the rest of the fields will be calculated by the program. The initial speed \( V_0 \), and its horizontal and vertical components are all shown near the bottom of the tab.
Experiment setup:
1 The 750 interface should be powered on (green light comes on).
2 The launcher should be plugged into power (white end glows) and its output should be plugged into input A of the 750.
3 Download and run the Projectile Motion program. Do NOT run it from the web, download it first. We are L10.
4 The apparatus should be set up as shown in the writeup for upward shots.
5 Be sure the point the ball leaves the tube is beyond the edge of your table.
6 You can set the angle by loosening the black thumb screw and screwing it into a different hole. Angles are separated by 15 degrees.

Calibrating launch velocity:
1 Decide who runs the computer, who launches the ball, and who catches it.
2 Adjust the angle to the desired value.
3 To launch the ball, hold the white cylinder (not the clear tube), pull out the washer at the end (see arrow at right in upward photo in the writeup) until the trigger clicks into the slot on the metal cylinder.
4 Drop the ball in the end of the tube.
5 On the action menu, select “Measure”. The “Run” light glows bright green.
6 Push the free end of the trigger bar on the side of the white cylinder to fire.
7 If not already there, go to the “Graph” tab. You should see a squarish peak near the left end in the blue plot. If not, something is wrong. Try again. If you still don’t see this, ask for help.
8 You can repeat this several times (select Measure, hit Run, drop the ball) to see that the peak appears very similar each time.
9 On the graph control (found at top left of graph, see picture above), select the cross-hair-shaped option at the far left. This lets you click on and move the vertical red dotted line back and forth. The cursor will change to vertical lines with arrows when you are close enough to the red line to grab it. Press and hold the left mouse button to move the red line. Notice that as you move the red line, the boxes above the graph show you the X and Y position of the marker.
10 Position the red line on a point about 1/2 way up the left side of the peak and click the “RISE” button.
11 Position the red line on a point about 1/2 way down the right side of the peak and click the “FALL” button.
12 Go to the “Results” tab.
13 Enter the angle (measured from the horizontal in degrees) in the appropriate box.
14 Select “Analyze Data” from the action menu. Numbers will appear in the boxes for speed and $V_0 \times \sin \theta$ and $V_0 \times \cos \theta$. Record these on your report.

Making a prediction:
1 Measure the distance that the center of the ball falls.
2 Use the formulas in the writeup to calculate the flight time and the range of the ball. Record these in your report. Under Windows, “Start”, then “Program”, then “Accessories” will lead you to a calculator program. In the calculator menu, select “View”, then “Scientific” for trig functions, square root, etc.

Checking your prediction:
1 Adjust the angle to the desired value.
2 Do a test shot first to see where to put the clipboard. The ball should hit near the center of the clipboard. Place a blank sheet of paper and above it carbon paper, carbon side down, on the clipboard, both clipped down.
3 Set the angle and fire away! Do several shots to look for variation. Be careful that neither the launcher nor the clipboard move between shots.
4 Mark all the spots you made with the angle used.
5 Hold the plumb-bob so it touches the floor at a point right below where the center of the ball is when it leaves the tube (use yellow lines to position the string). Measure from this point to the middle of the spots you got with your shots.
6 Record your results in your report and answer the questions.

Downward shooting:
1 Pull the insert with the rod out of the clear plastic tube (hold the clear plastic tube while twisting and pulling on the white cylinder to remove the assembly).
2 Rotate the apparatus and reclamp to the table.
3 Adjust the angle to the desired value.
4 Click the “Run” button, then drop the ball in the end of the tube so it rolls down.
5 Repeat the above analysis procedure for at least one angle of downward shooting.

Learning LabView Graph Controls
For future experiments, we’ll do much more complicated graph manipulations. Take time now to play with them.
1 Select expand (center icon with magnifying glass at top left of plot).
2 Press left mouse button, then select horizontal expand (top center icon in submenu), then release mouse button.
3 Put cursor (now like a magnifying glass) to one side of the blue peak, press left mouse button, hold and move to the other side of the peak, release mouse button. Region you selected expands to fill plot.
4 Go back to cursor mode (crosshair icon) and move red line around.
5 Under expand (magnifying glass icon), select full screen (bottom left icon in submenu). You should see the full plot on your screen again.
6 Now expand a region not including the red line. The red line disappears!
7 Go back to full screen, go back to cursor mode and move the red line somewhere else.
8 Go to expand mode and blow up a region including the red line.
9 In the future, when you need to use a cursor in an expanded region, don’t forget to move the vertical lines into the desired region before expanding.

If you finish early, you are encouraged to play with the equipment and the LabView controls or try different angles, either upward or downward, but don’t forget to finish your report.