Projectile Motion (5/31/2019) (approx. completion time for just parts A & B: 1.5 h; for entire lab: 2.3 h)

EQUIPMENT NEEDED:

- Mini Launcher and steel ball
- plumb bob
- pushrod
- meter stick
- carbon paper
- white paper
- C-clamp
- masking tape
- eye protection
- ball stop (box)
- Min Luncher Manual

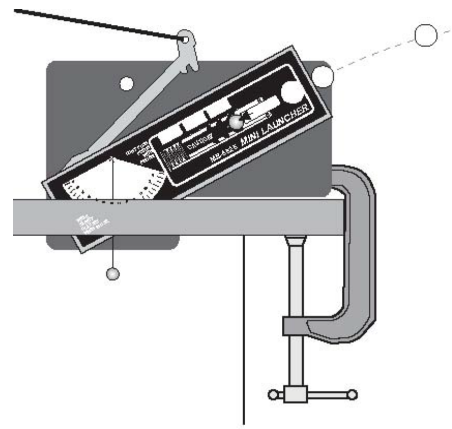

Figure 1.1: Setup to shoot horizontally off table

Purpose

The purpose of this experiment is to predict and verify the range of a ball launched at an angle. The initial velocity of the ball is determined by shooting it horizontally and measuring the range and the height of the Launcher.

Theory

To predict where a ball will land on the floor when it is shot off a table at an angle, it is necessary to first determine the initial speed (muzzle velocity) of the ball. This can be determined by launching the ball horizontally off the table and measuring the vertical and horizontal distances through which the ball travels. Then the initial velocity can be used to calculate where the ball will land when the ball is shot at an angle.

INITIAL HORIZONTAL VELOCITY:

For a ball launched horizontally off a table with an initial speed, v_0, the horizontal distance travelled by the ball is given by $d_x = v_0 t$ where t is the time the ball is in the air. Air friction is assumed to be negligible.

The vertical distance the ball drops in time t is given by $d_y = V_{oy}t + 1/2\, a_y t^2$.
The initial velocity of the ball can be determined by measuring x and y. The time of flight of the ball can be found using: $t = (2d_y/a_y)^{1/2}$ and $d_x = V_{ox}t + 1/2\, a_x t^2$

Then the initial velocity can be found using $v_{0x} = d_x/((2d_y/a_y)^{1/2})$

INITIAL VELOCITY AT AN ANGLE:

To predict the range, d_x, of a ball launched with an initial velocity at an angle, θ, above the horizontal, first predict the time of flight using the equation for the vertical motion:

$$d_y = (V_o \sin\theta)t + 1/2\, a_y t^2 \quad \textbf{and} \quad d_x = (V_o \cos\theta)t + 1/2\, a_x t^2$$

where d_{yo} is the initial height of the ball and d_{yf} is the position of the ball when it hits the floor.

SAFETY REMINDERS

Projectiles can cause serious injury. Do not load launcher until it's safe to fire.

CAUTIONS: EYE PROTECTION RECOMMENDED BEFORE FIRING LAUNCHER!

DO NOT AIM LAUNCHER AT GLASS DOOR PANES!

Setup ① Clamp the Mini Launcher near one end of a sturdy table as shown in Figure 1.1.

② Adjust the angle of the Mini Launcher to zero degrees so the ball will be shot off horizontally.

③ Position a ball stop (i.e. a box) such that it will catch the ball after it lands.

Procedure

Part A: Determining the Initial Velocity of the Ball

① Put the ball into the Mini Launcher and cock it to the midrange position (2 clicks). Fire one shot to locate where the ball hits the floor. At this position, tape a piece of white scrap paper to the floor using masking tape. Place a piece of carbon paper (carbon-side down) on top of this paper then tape a protective piece of white paper over the carbon paper. (Avoid taping to the carbon paper as it can be reused if not torn.) When the ball hits the floor, it will leave a mark on the bottom white paper.

② Fire about ten shots then remove the top paper and carbon paper to make sure you have good marks.

③ Measure the vertical distance from the bottom of the ball as it leaves the barrel (this position is marked on the side of the barrel) to the floor. Record this distance in Table 1.1.

④ Use a plumb bob to find the point on the floor that is directly beneath the release point on the barrel. Measure the horizontal distance along the floor from this point to the leading edge of the paper. Record in Table 1.1.

⑤ Measure from the leading edge of the paper to each of the ten dots and record these distances in Table 1.1.

⑥ Find the average of the ten distances and record the value in Table 1.1.

⑦ Using the vertical distance calculate the time of flight. Record it in Table 1.1.

⑧ Calculate the Average Total Distance (i.e. Distance to paper edge + Average Distance) and record it in Table 1.1. Calculate the average initial velocity. Record it in Table 1.1.

Table 1.1 Determining the Initial Velocity

Vertical distance = ______________ Horizontal distance from release point to paper edge = _____________

Calculated time of flight = __________ Average initial velocity = ________________

Trial Number	Distance
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average Distance from Edge	
Average Total Distance	

Part B: Predicting the Range of the Ball Shot at an Angle

① Adjust the Mini Launcher to launch at an angle between 20 and 60 degrees above the horizontal. Record this angle in Table 1.2.

② Using the initial velocity and vertical distance found in Part A of this experiment, calculate the new time of flight and the new horizontal range for a projectile launched at the new angle. Record them in Table 1.2.

③ Draw a line across the middle of a white piece of paper and tape the paper on the floor so the line is at the predicted horizontal distance from the launch point. Cover the paper with carbon paper and a top sheet of white paper as before.

④ Shoot the ball ten times.

⑤ Measure the ten distances and take the average. Record these in Table 1.2.

Analysis

① Calculate the Average Total Distance. Record it in Table 1.2.
(Average Total Distance = Distance from Edge of Paper + Horizontal Distance to paper edge.)

② Calculate the percent difference between the predicted range and the resulting average total horizontal distance when shot at an angle. Record it in Table 1.2.

③ Estimate the precision of the predicted range. How many of the final 10 shots landed within this range?

Table 1.2 Confirming the Predicted Range

Angle above horizontal = _______________ Horizontal distance to paper edge = _____________

Calculated time of flight = ______________ Predicted (i.e. Calculated) Range (PR) = _____________

Calculated % difference between predicted range and ave. measured range (MR): (PR-MR)÷MR=_____________

Trial Number	Distance from Edge of Paper
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average Distance from Edge	
Average Total Distance	

Part C: Predicting the Range of the Ball Shot at a Negative Angle

① Adjust the Mini Launcher to launch at an angle between 10 and 40 degrees below the horizontal and record this angle in Table 1.3.

② Using the initial velocity and vertical distance found in Part A of this experiment, calculate the new time of flight and the new horizontal range for a projectile launched at the new angle. Record it in Table 1.3.

③ Draw a line across the middle of a white piece of paper and tape the paper on the floor so the line is at the predicted horizontal distance from the launch point. Cover the paper with carbon paper and a top sheet as before.

④ Shoot the ball ten times.

⑤ Measure the ten distances and take the average. Record these in Table 1.3.

Analysis

① Calculate the Average Total Distance. Record it in Table 1.3.
(Average Total Distance = Distance from Edge of Paper + Horizontal Distance to paper edge.)

② Calculate and the percent difference between the predicted range and the resulting average total distance when shot at an angle.

③ Estimate the precision of the predicted range. How many of the final 10 shots landed within this range?

Table 1.3 Confirming the Predicted Range

Angle below horizontal = _______________ Horizontal distance to paper edge = _____________

Calculated time of flight = ______________ Predicted Range (PR) = ________________

Calculated % difference between predicted range and ave. measured range (MR): (PR-MR)÷MR=_____________

Trial Number	Distance from Edge of Paper
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Average Total Distance	

Part D: Predicting the Maximum Range Angle of the Ball

① Consider that the launcher is elevated above the floor on the lab table and predict whether the maximum range of the projectile will occur below an angle of 45°, at the angle of 45°, or above an angle of 45°:________________. (You may want to sketch a picture to help you make your prediction.)

② Pick a range of angles between 0° and 90° above the horizontal to test for range vs. angle. (Choose wisely.)

③ Adjust the Mini Launcher to do test firings at each of these angles. Do at least 4 trial shots at each angle.

④ Use your data to estimate what you think will be the launch angle to achieve maximum range. List your estimated launch angle for maximum range here:________________. Lay down paper and carbon paper as before and do 10 trials at this angle.

⑤ Measure the horizontal distance from the launch point to the edge of the paper and the 10 distances from the edge of the page as before, and record them in Table 1.4.

Analysis

① Calculate the average maximum range (i.e. average total distance) and record in Table 1.4 below.
② Derive an expression for the range as a function of launch angle, elevation (i.e. vertical distance above floor) and initial velocity.

③ Graph the range versus launch angle (for your launch elevation and initial velocity) on a calculator or other graphing software and find the launch angle for maximum range from theory (i.e. calculator graph):_____________.
④ How does this value compare with your estimated launch angle of maximum range from your data (i.e. % difference)?_________________________.
⑤ What is the maximum range predicted from theory for your elevation and initial velocity? _________________
⑥ How does the theoretically predicted maximum range compare to the Average Total Distance (below)?

Table 1.4 Data for Estimated Maximum Range Launch Angle

Horizontal distance to paper edge = _______________ Vertical distance________________ Initial velocity___________

Average range from measurements at estimated maximum range angle (i.e. Average Total Distance): _______________

Trial Number	Distance from Edge of Paper
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Average Total Distance	