LAB 4
Projectiles

OBJECTIVES

1. Measure the initial velocity of a ball launcher three different ways: horizontal projectile, photogate projectile, and vertical projectile.
2. From your data uncertainties, propagate the data's uncertainty to the velocity's uncertainty. Plot distribution curves to determine if measurements are consistent or inconsistent with each other.

EQUIPMENT

Ball, launcher, meter stick, laser photogate timer, calipers, soft target.

THEORY

Projectile motion is the motion of a particle that is in free-fall with a nonzero horizontal velocity where its horizontal acceleration is zero ($a_x = 0$) and vertical acceleration is the free-fall acceleration ($a_y = -g$). The Projectile equations are

$$\underbrace{\Delta x = v_{x0}t;}_{x-\text{direction}} \qquad \underbrace{\Delta y = v_{y0}t + \tfrac{1}{2}a_y t^2; \qquad v_y = v_{y0} + a_y t; \qquad v_y^2 = v_{0y}^2 + 2a_y\Delta y}_{y-\text{direction}}$$

PROCEDURE

Part 1 Measuring the Muzzle Velocity of a Launcher

Part 1A: Horizontal Projection Velocity $v_{avg,2}$

a. Fire the ball horizontally from the launcher ten times and measure its average range and initial height. Calculate the average range x_{avg}, standard deviation S_x, and uncertainty σ_x.
b. **Plot** a distribution curve for a $1S_x$-confidence interval ($x_{avg} \pm S_x$) and determine how many fell within this confidence interval. Was this 7/10?
c. **Calculate** the time of flight (hint: use y_0 and v_{0y}) of the ball. Using the time of flight and x_{avg} determine the initial speed of the ball $\mathbf{v_{avg,2}}$.
d. **Calculate** the (i) percent uncertainty $\%\sigma_2 = 100\cdot\sigma_2/ v_{avg,2} = 100\cdot\sigma_x/ x_{avg}$ and the (ii) uncertainty $\sigma_2 = v_{avg,2}\cdot\sigma_x/ x_{avg}$. Your best value for the velocity is $v_{avg,2} \pm 2\sigma_2$. Record your results in the table in Part (2).

Part 1B: Vertical Projection Velocity $v_{avg,3}$

a. Fire the ball vertically from the launcher ten times and measure the maximum height it reaches. Calculate the average height change Δy_{avg}, standard deviation S_y, and uncertainty σ_y.
b. Plot a distribution curve for a $1S_y$-confidence interval ($\Delta y_{avg} \pm S_y$) and determine how many fell within this confidence interval. Was this 7/10?
c. Calculate the (i) average initial velocity $\mathbf{v_{avg,3}}$, (ii) percent standard error $\%\sigma_3 = 100\cdot\sigma_y/2\Delta y_{avg}$, and (iii) standard error $\sigma_3 = v_{avg,3}\cdot\sigma_y/2\Delta y_{avg}$. Your best value for the velocity is $v_{avg,3} \pm 2\sigma_3$. Record your results in the table in Part (2).

Part 2: Comparison of Velocities

a. **Create a table** with columns of the average velocities v_{avg}, uncertainty 2σ, and percent uncertainty $\%\sigma$, including ($v_{avg,1}$, $2\sigma_1$, $\%\sigma_1$) from Lab 3.
b. On a single scaled graph (drawn by hand), **plot all 3 distribution curves** where all of the distribution curves are drawn to the same height but their widths are determined by the uncertainty. That is, a small uncertainty implies a thin distribution curve whereas a larger uncertainty has a wide distribution curve.
c. By looking at this table, compare the results with the following questions:

- Do any of the measurements overlap? Are they consistent or inconsistent with each other?
- Which measurement is most precise? Does this mean that it is the most accurate?
- Which has the most significant figures? Does this mean that it is the most accurate?
- For each measurement, discuss possible sources of uncertainties including systematic ones. Which of these velocities is most reliable? Does your "gut feeling" agree with your answer?
- Using the above information, what is your best estimate of the muzzle velocity of the launcher? What value would you choose for further calculations if your life depended on the results? Would you pick one of the three measured values or use some combination of the three?

Explain your reasoning for each part.

Part 3: Challenge Shot

Using your launcher and results from Lab 3 (Part 1D), **predict how far away (x_{thy}) the ball catcher must be placed from the launcher.**

a. The launcher must be placed on the floor and fired up to the different height of the ball catcher. Here is the necessary data for you:
   i. Measure the height change from launcher to ball catcher
   ii. Set the launch angle (set by you) between $0^o - 75^o$
   iii. Initial velocity v_0 is determined from the results of Part (1D).

b. **Predict the flight time t_{thy}** of the ball. Sketch the trajectory of the ball and show the locations of these two times predicted times. Which time is applicable for your shot? Explain your reasoning.

c. Place the ball catcher at your predicted landing spot and notify an instructor before firing the ball. **The challenge is that you only have one shot to make it into the ball catcher.** Hint: you need to shoot straight to make it into the ball catcher!

d. How closely did your shot come to the target?