PHY-110 **Spring 2025**

Group Members: _____

Lab 5: The Ballistic Pendulum – application of conservation of momentum and conservation of energy.

Goals

- Determine the speed of a ball launched from a projectile launcher.
- Apply conservations of momentum and energy to derive applicable equations.
- Compare the measured speed from a derived equation to that measured with a photogate.

The Ballistic Pendulum

Before the invention of radar, armies would measure the speed that a cannon ball is shot from the cannon, or the "muzzle speed" of a rifle by firing them into a pendulum and measuring how high the pendulum swung. The calculation requires analysis of the collision between the ball and pendulum, followed by the conservation of energy in the swing of the pendulum.

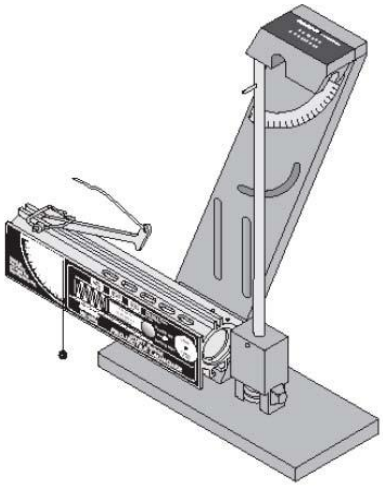

Figure 1: The ballistic pendulum apparatus.

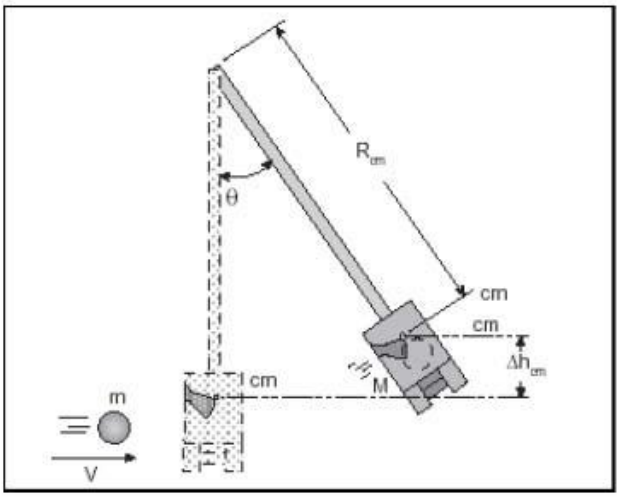

Figure 2: A ball of mass, *m*, and speed, *v*, is caught by the pendulum, which swings up to an angle θ.

Theory

Part I: The collision between the ball and the pendulum

A ball of mass *m*, moving at initial speed v_0, collides with and is captured by a pendulum of mass *M*. After the collision, the ball plus pendulum move together at a final speed of v_f.

After the collision, the pendulum, with ball inside, swings upward until it comes to a stop, when its center of mass reaches a height *h* above its initial position (see Figure 2).

Write down the expression of v_0 you obtained in the exercise on the "Ballistic Pendulum" in terms of *m*, *M* and *h*.

Part II: Relation between height *h* and pendulum angle θ

Instead of measuring the height of the center of mass, you will measure the maximum angle that the pendulum swings. Use Figure 2 to derive an equation that relates the angle, θ, of the pendulum to the height, h, and the length, R_{cm}, of the pendulum to its center of mass.

Part III: Deriving the final equation

By using substitution, algebraically combine the equations in Parts I and II to derive an equation relating the initial velocity of the ball, v_0, to the maximum angle of the pendulum, θ, the mass of the ball, m, the mass of the pendulum, M, and the pendulum length to the ball+pendulum center of mass, R_{cm}.

The Experiment

A: Using the Ballistic Pendulum to determine the muzzle velocity:

1. Remove the pendulum and obtain and record the masses of the ball and pendulum, and estimate the uncertainties.
2. Determine the center of mass of the pendulum *with the ball in it* by finding the point where it best balances on the edge of a ruler. Measure the distance from the pivot point to this balance point, including your estimate of the uncertainty.
3. Reattach the pendulum, insert the ball into the launcher, and cock it to long range.
4. Let the pendulum hang at its vertical position and move the angle indicator to zero degrees. Fire the launcher and note and record the angle reached.
5. Reload the launcher and set the angle indicator to an angle of 5^o less than that reached in step 4. This will nearly eliminate the drag on the pendulum caused by the angle indicator.
6. Fire the launcher and record the angle reached by the pendulum.
7. Repeat steps 5 and 6, completing 10 trials.
8. Input the expression you derived in Part III above into Excel to calculate the muzzle speed of the launcher for each trial. Calculate the average speed v_0 and uncertainty. Remember that the uncertainty in a measurement x after N trials is:

$$\delta x = \frac{\sigma}{\sqrt{N}}$$

B: Determining the Muzzle Velocity using a photogate

1. Remove the pendulum from the apparatus and place the photogate so that the full diameter of the ball passes through the gate immediately after leaving the launcher.
2. Use the calipers to measure the diameter of the ball.
3. Open Capstone (then click on "remind me later" in the first window)

   Click "hardware setup" in the upper left.

   Click on port 1 in the image.

   Under hardware setup choose *photogate, one flag*.

   Click on the blue cog in the lower right corner of the hardware setup dialog box and set the flag width to the width of the ball.

   Click "ok" in the dialog box.

   Click "hardware setup" again to make hard hardware setup box go away.

   Select "classic templates" and choose the first option (includes a table).

   In the table, click on "select measurements" and choose speed (m/s) and time in gate (in ms) for the two columns.

   Load the ball in the long-range setting.

   Click "Record" (in lower left corner) and fire the ball through the photogate, then click "Stop"

   Note and record the measured speed of the ball.

   Obtain 10 measurements with the photogate, the average and uncertainty.

C. Compare your results using the different methods.

How does your measured velocity, with uncertainty, using the ballistic pendulum compare with that measured with the photogate? Do the ranges of the values with uncertainties overlap?