The Ballistic Pendulum

1 Introduction

In this experiment you will determine the muzzle velocity of a gun using two different methods. The first method consists of applying kinematics to determine the muzzle velocity of a ball fired horizontally from the table top by measuring the range of the ball and the height of the gun. In the second part of the experiment, the ball will be fired into the ballistic pendulum shown in Figure 1 and the muzzle velocity will be determined by measuring the angle that the pendulum rises and applying conservation principles.
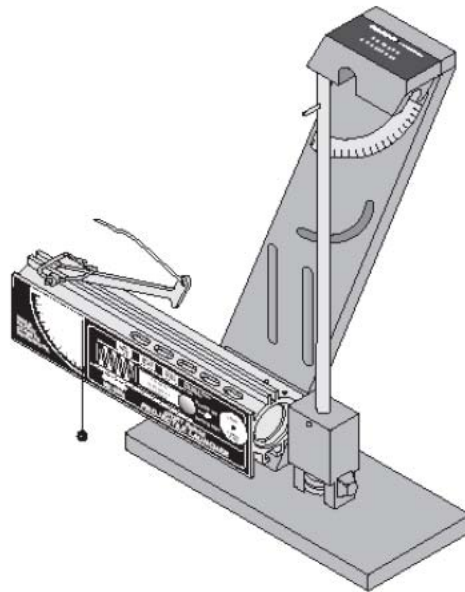

Figure 1: The ballistic pendulum.

2 Prelab Exercises

2.1 Derivation of Muzzle Velocity from Projectile Kinematics

Consider the situation shown in Figure 2. A ball is fired horizontally with a velocity, v, from a height, y, above the floor and hits the floor a horizontal distance, x, from the launcher. Derive an expression for v in terms of x and y.
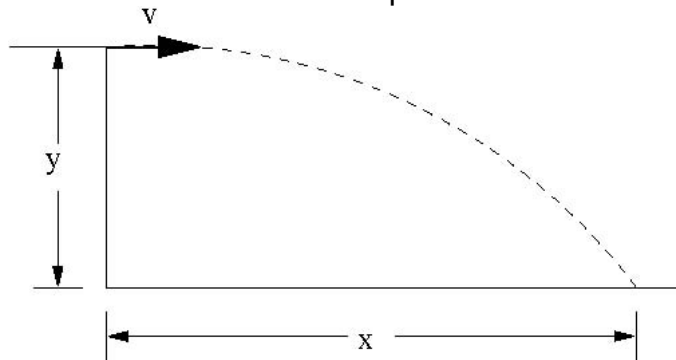

Figure 2: A ball is fired horizontally with a velocity, v, from a height, y, and travels a distance, x.

2.2 Derivation of Muzzle Velocity from the Ballistic Pendulum

Suppose a ball of mass, m, is fired with a velocity, v, and caught by the ballistic pendulum as shown in Figure 3. Apply conservation principles to derive an expression for v in terms of the mass of the ball, m, the combined mass of the pendulum and ball, M, the length of the pendulum rod from the pivot point to the center of mass of the pendulum, R_{cm}, the strength of the gravitational field, g, and the angle of the pendulum swing, θ.
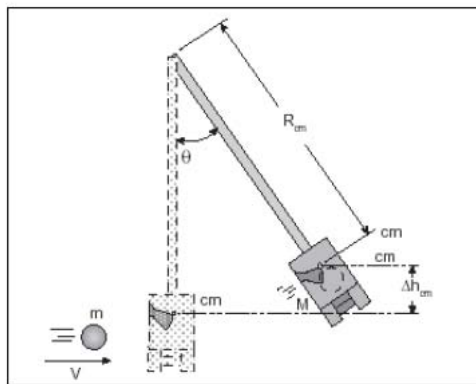

Figure 3: A ball of mass, m, and velocity, v, is caught by the ballistic pendulum.

3 The Experiment

3.1 Determining Muzzle Velocity from Projectile Kinematics

1. Clamp the ballistic pendulum near one end of the table with the launcher aimed away from the table and secure the pendulum up out of the path of the ball.
2. Place the metal ball in the launcher and use the ramrod to cock the piston to medium range.
3. Fire the gun and note where the ball lands.
4. Tape a sheet of white paper to the floor at the point of impact and place a piece of carbon paper on top of it.
5. Fire the gun ten times, making sure that marks are being made on your paper.
6. Measure and record in a data table the distance from the point directly below the release point of the ball to each of your ten marks.
7. Determine the average horizontal distance, x, the ball travels. Also, calculate the standard deviation of your measurements and use this as the uncertainty, Δx, in your measurement of x. Record the result as $x \pm \Delta x$.
8. Measure and record the vertical distance, y, the ball falls. Estimate the uncertainty in this measurement, Δy, and record your measurement as $y \pm \Delta y$.

9. Use the expression you derived in Section 2.1 with the average value for x and the measured value for y to determine the muzzle velocity, v. Also, determine the uncertainty in v from the uncertainties in x and y and record the result as $v \pm \Delta v$.

3.2 Determining Muzzle Velocity Using the Ballistic Pendulum

1. Load and cock the launcher to medium range.
2. Return the pendulum to its vertical position and move the angle indicator to zero degrees.
3. Fire the launcher and note the angle reached.
4. Load the launcher, then set the angle indicator to an angle of 12° less than that reached in step 3. This will nearly eliminate the drag on the pendulum caused by the indicator, since the pendulum will only move the indicator the last few degrees.
5. Fire the launcher and record the angle reached by the pendulum.
6. Repeat steps 4 and 5 and record the angle each time to get a total of ten angle measurements.
7. Determine the average angle. Also, calculate the average deviation of your measurements and use this as the uncertainty, $\Delta\theta$, in your measurement of θ. Record the result as $\theta \pm \Delta\theta$.
8. Remove the pendulum from the base by unscrewing and removing the pivot axle.
9. Measure the mass of the pendulum and ball together, estimate the uncertainty, and record the result as $M \pm \Delta M$.

10. Measure the mass of the ball, estimate the uncertainty, and record the result as m $\pm\Delta$m.

11. Determine the center of mass of the pendulum with the ball by balancing it on the edge of a ruler. Measure the distance from the pivot point to this balance point, estimate the uncertainty, and record it as $R_{cm} \pm\Delta R_{cm}$.

12. Use the expression you derived in Section 2.2 with the data you measured in this section to calculate the muzzle velocity of the launcher. Also, determine the uncertainty in v from the uncertainties of your measurements and record the result as v$\pm \Delta$v.

4 Questions

1. Do the values for the muzzle velocity determined using the two different methods agree to within experimental uncertainties? Calculate a percent difference.

2. What sources of error are there in this experiment? How much do these errors affect your results?

3. What percentage of the kinetic energy is lost in the collision between the ball and the pendulum? Would it be valid to assume that kinetic energy was conserved in the collision?

4. How does the angle reached by the pendulum change if the ball is not caught by the pendulum? You may test this by turning the pendulum around so the ball strikes the back of the catcher. Is there more energy or less energy transferred to the pendulum?