**Experiment**

**7**

# Ballistic Pendulum

**Introduction**

The purpose of this experiment is to determine the muzzle velocity of a projectile launcher using two different experimental techniques.

Method 1

The muzzle velocity will be determined by measuring the horizontal distance and vertical distance of a projectile that is fired in the horizontal direction.

Method 2

The muzzle velocity of the projectile launcher will be determined using the ballistic pendulum, by applying the concepts of conservation of energy and momentum to the system.

## **Theory**

1. One can calculate the muzzle velocity of the projectile launcher from the measured range of the projectile and the distance traveled in the vertical direction. Using the equation governing the horizontal motion of a projectile fired in the horizontal direction, derive an expression for the initial velocity of the projectile in terms of the range of the projectile, Δx and its vertical distance, Δy. We’ll call this equation 1. Explain your equation.

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1. Using the law of conservation of mechanical energy and the law of conservation of momentum, derive an expression for muzzle velocity of a projectile that is fired horizontally into a pendulum in terms of the mass of the projectile, m, and pendulum, M, the maximum angle reached by the pendulum, **θ**, and the length of the pendulum Rcm. Show this stepwise derivation in the space below. Indicate in words where you have applied the law of conservation of momentum and the law of conservation of mechanical energy. We’ll call this equation 2.

### Procedure

**PART 1: Method 1**

1. Draw a line across the middle of a white piece of paper on the floor so the line is at the landing site (look for dents in floor). Then cover the paper with carbon paper.
2. Measure, ΔX0, the distance from launch position to end of base. Record your result in the Data section.
3. Put the steel ball into the Projectile Launcher and lock it to long range. Set =0o.
4. Shoot the ball, and record the horizontal distance, X, from the plumb bob to the landing spot of the ball in Table 1.
5. Repeat steps 2 and 3 four more times at the same angle above. Record range in Table 1.
6. Calculate the average range. Then record this value in Table 1.
7. Measure the vertical displacement of the center of the ball (the initial position of the ball is marked on the side of the barrel), YTotal. This is measured in two parts; ΔY0, vertical distance from launch position to top of table, and ΔY, vertical distance from top of table to floor.
8. Calculate the initial speed using equation 1 that you derived in the theory and record it in the data section of Part 1.

**Part 2: Method 2**

Diagram, engineering drawing

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1. Measure the mass of the ball, m, and the mass of the pendulum. Record them in the data section Part 2.
2. Clamp the pendulum base to the table. Place the pendulum in the base by screwing the pivot axle to allow the pendulum to hang freely. Make sure that the clamp does not interfere with the pendulum swing.
3. Measure the distance from the pivot point to the red dot in the pendulum (center of mass) and record it as Rcm in Table 2.
4. Latch the pendulum at 90° so it is out of the way, then load the projectile launcher to the ballistic pendulum mount at the level of the ball catcher.
5. Put the steel ball into the Projectile Launcher and lock it to the same range in Part 1. Move the angle indicator to zero degrees.
6. Fire the launcher horizontally and see how high the angle has reached.
7. Load the launcher, then set the angle indicator to an angle 1-2° less than that reached in step 5. This will nearly eliminate the drag on the pendulum caused by the indicator, since the pendulum will only move the indicator for the last few degrees.
8. Fire the launcher, and record the angle reached by the pendulum in Table 2. Repeat this measurement four more times, setting the angle indicator to a point 1-2° below the previous angle reached by the pendulum each time.
9. Calculate the average angle and initial speed of the ball (use equation 2). Record them in Table 2.

**Analysis**

**PART 1: Method 1**

1. Calculate the uncertainty in ΔX. Show all work.
2. Calculate the uncertainty in ΔXTotal. Show all work.
3. Calculate the uncertainty in ΔYTotal. Show all work.
4. Calculate the muzzle velocity of the ballistic pendulum using equation (1). Show all work.
5. Derive the expression for the uncertainty in the muzzle velocity of the ballistic pendulum that was obtained from equation (1). Then calculate its value. Show all work.

**PART 2: Method 2**

1. Calculate the uncertainty in θ. Show all work.
2. Calculate the muzzle velocity of the ballistic pendulum using equation (1). Show all work.
3. Derive the expression for the uncertainty in the muzzle velocity of the ballistic pendulum that was obtained from equation (2). Then calculate its value. Show all work.

**Data and Results**

**Part 1: Method 1**

ΔX0 (distance from launch position to end of base) = \_\_\_\_\_.232m\_\_\_\_\_\_\_\_

#### **Table 1**

g=9.8006m/s2 (3 significant figures)

|  |  |
| --- | --- |
| Trial | Δx (m) |
| 1 | 2.452 |
| 2 | 2.372 |
| 3 | 2.362 |
| 4 | 2.362 |
| 5 | 2.342 |
| Average & Uncertainty | 2.38 |

ΔXTotal =ΔX0 + ΔX =\_2.146+.232\_\_\_\_\_\_\_\_\_

ΔY0 (vertical distance from launch position to top of table) = \_\_\_.925m\_\_\_\_\_\_\_\_\_\_

ΔY (vertical distance from top of table to floor) = \_\_\_.075m\_\_\_\_\_\_\_\_\_\_

ΔYTotal=ΔYo+ΔY = \_1m\_\_\_\_\_\_\_\_\_\_\_\_

Uncertainty of range ****ΔXTotal =. \_\_.07m\_\_\_\_\_\_\_\_\_\_

Uncertainty of range ****Δ YTotal = \_\_\_.07\_\_\_\_\_\_\_\_\_

Muzzle velocity v = \_\_\_\_\_5.26\_\_\_\_\_\_\_±\_\_\_\_.02\_\_\_\_\_\_ (equation 1)

**Part 2: Method 2**

**Table 2**

|  |  |
| --- | --- |
| **Trial Number** | **Value (rads)** |
| θ1 | 38 |
| θ2 | 37 |
| θ3 | 38.5 |
| θ4 | 37 |
| θ5 | 37 |
| Average θ | 37.5 |
| m | 66.02 g |
| M | 236.3 |
| Rcm | 40 |

Standard deviation and uncertainty of

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Muzzle velocity v = \_\_\_\_\_5.75\_\_\_\_\_\_\_±\_\_\_\_\_.04\_\_\_\_\_ (equation 2)

# Conclusion

Your conclusion must include a description of the experiment and its purpose, a discussion and statement of results, a discussion of random errors and systematic errors. In addition, discuss

* the purpose of the experiment.
* the procedure.
* whether or not the results agree with each other (don’t forget to include any evidence in your discussion).
* the dominant source of error.

The conclusion must be in paragraph form; otherwise, ten percent of the total points will be deducted.

The purpose of this lab was to explore the concepts of kinematic velocity, kinetic energy, and potential energy and determine how they could be used in conjunction to confirm muzzle velocity.

For case one, we are expected to find the muzzle velocity using the time it takes for an object to fall from a specific height. Using , and knowing that horizontal movement is constant due to the lack of horizontal acceleration (there is nothing to increase the speed in a horizontal direction) , we can determine the time it takes for an object to drop from a specific height regardless of the initial velocity. Finding the time for the object to drop to be roughly 0.451754, we can use that time to find the initial velocity using the kinematic equation . Having measured to be 2.38m, we use the formula and solve for muzzle velocity.

Case two of this lab focuses on verifying that muzzle velocity through conservation of energy. We know , we can set kinetic energy = to potential energy and measure the height the pendulum reaches when the gun is fired at it. So, the mass of the system, times gravity, times the height, should equal the . Using this method we found the velocity to equal 5.75m/s, which is relatively similar to the value of 5.26m/s we found in the kinematic equation evaluation.

The results are within a reasonable spectrum of agreement. The sources of error for this lab must include the instruments that we were given. There existed guns within the experiment that fired at a much lower muzzle velocity rate than the gun our group used. Due to the lack of guns available and the volume of students attempting to complete this lab, we settled for a potentially faulty gun. Another issue is the cocking position of the gun. Often times our bullet would “roll forward” within the chamber prior to pulling the trigger. This means the ball would not receive the full momentum of the spring as the gun is fired. Instead, the spring would contact our ball some distance down the shaft and only then push the ball out of the muzzle.