

Name: \_\_\_\_\_

## LAB 4. PROJECTILE RANGE

In this activity you will clamp the launcher to a table and fire a projectile onto the floor from different initial angles. You will then compare the observed trajectories to predictions from a simple ballistic model.

### Supplies

Projectile launcher, projectile, ramrod, clamp, plumb line, measuring tape, meter stick, carbon paper, white paper, tape, sturdy table

### Safety considerations

- The projectile launcher fires a 1-inch steel or hard plastic ball at speeds that can be considerable. To avoid eye injury, **everyone in the room must wear safety glasses or goggles at all times.**
- **Never look down the muzzle** of the barrel. You can see into the barrel through the slots cut in the sides.
- Once the barrel is loaded, be careful not to place any part of your body in front of the launcher.
- Use the ramrod for loading and cocking the launcher. **Never** poke your fingers into the barrel—you could very easily break them! That would be bad.
- Load the projectile launcher with 1" balls only. Other loads may cause dangerous conditions.

### Using the projectile launcher

#### Description

The projectile launcher propels its load using a cocked spring. The spring can be set at three positions, each with increasing force and travel distance. The barrel pivots up and down to adjust the firing angle. An angle gauge with a small built-in plumb line measures the firing angle. The muzzle is the end of the barrel close to the pivot.

#### Care of the launcher

Do not fire the launcher without a projectile. Such a “dry fire” may damage the launcher. If you wish to release a cocked spring without firing, insert the ramrod into the barrel against the cradle and, while holding the ramrod firmly, release the trigger. Slowly pull the ramrod out of the barrel.

Do not over tighten the wing nuts; they can easily strip and break.

#### Setup

Place the launcher at the edge of the table with the muzzle of the barrel pointing away from the table. Clear the line of fire so that the trajectory is not obstructed.

Clamp the launcher firmly to the table. Use two clamps, one on either side of the base, if available. If only one clamp is available, put it on the side under the barrel of the launcher.

**Firing**

1. Place the projectile into the muzzle of the launcher. Push it into the barrel using the ramrod. As you push it in, the trigger on the top of the barrel will rise and fall with a click up to three times. After each click, the launcher is cocked in that position.
2. If the barrel is horizontal, check that the projectile is against the cradle by looking through the slots in the side of the barrel. If the projectile has rolled forward, gently push it back against the cradle with the ramrod.
3. Check that no one is in the line of fire.
4. Announce intention to fire with a countdown from “3.”
5. After calling “1,” fire the launcher by pulling up on the trigger.
6. Watch the projectile as it travels and bounces so that you can retrieve it.

**Lab activities and measurements****Data sheet**

Enter your measurements into your approved data sheet.

**Activity 1. Finding launch speed**

In this activity, you will fire five shots horizontally off the table onto the floor and measure the distance traveled. Assuming the projectiles accelerate downward with magnitude  $g$ , you will calculate how long they were in the air, and thus how fast they were moving horizontally.

1. Adjust the barrel to fire horizontally.
2. Measure the height of the muzzle above the floor. *Record the height in your data sheet.*
3. Using the plumb line, find the point on the floor directly beneath the muzzle. Mark this point with tape.
4. Load, cock, and fire the launcher. Note where the projectile lands.
5. Tape a piece of white paper onto the floor where you saw the projectile land. Place a piece of carbon paper, carbon side down, atop it. Place another piece of white paper atop the carbon paper to protect it from tearing.
6. Check that the launch angle is still horizontal. Adjust if not.
7. Load, cock, and fire the launcher.
8. The projectile should have landed on the paper and made a mark on the white paper on the floor. Leaving this paper taped to the floor, find the mark and label it.
9. Replace the carbon paper and protective sheet.
10. Repeat steps 6–9 for a total of five shots onto the paper.
11. Measure the distances from the point on the floor beneath the muzzle to the shots on the paper. *Record these distances on your data sheet.*

**Activity 2. Range**

In this activity, you will launch the projectile five times each at angles of  $10^\circ$ ,  $20^\circ$ ,  $30^\circ$ ,  $40^\circ$ ,  $50^\circ$ , and  $60^\circ$  to find how range (horizontal travel distance before landing) varies in response to launch

angle. You will then try two more launch angles to get closer to the angle giving the longest range.

1. Set the launch angle to the desired value.
2. Load, cock, and fire the launcher. Note where the projectile lands.
3. Tape a piece of white paper onto the floor where you saw the projectile land. Place a piece of carbon paper, carbon side down, atop it. Place another piece of white paper atop the carbon paper to protect it from tearing.
4. Check that the barrel is still at the desired angle. Adjust if not.
5. Load, cock, and fire the launcher.
6. The projectile should have landed on the paper and made a mark on the white paper on the floor. Leaving this paper taped to the floor, find the mark and label it.
7. Replace the carbon paper.
8. Repeat steps 4–7 for a total of five shots onto the paper.
9. Measure the distances from the point on the floor beneath the muzzle to the shots on the paper. *Record these distances on your data sheet.*
10. Choose two additional launch angles to try to find the maximum range. Fire five shots from each angle and *record the distances on your data sheet.*

### **Processing, Analysis, and Interpretation**

You will find how well your measurements correspond to a simple ballistic model of the system. Assume that the launcher fires the projectile at the same speed for every launch angle, and that the projectile in flight is subject only to the force of gravity. First, using the data from the horizontal launches, you will deduce the muzzle speed of the projectile. You will then use that muzzle speed to predict the range of the projectile at different launch angles, and compare that prediction to your observations.

You will want a spreadsheet to process and analyze your data. You may use Google Sheets.

#### **Activity 1. Finding projectile speed**

##### ***Drop time***

1. Enter the muzzle height into your spreadsheet.
2. Enter the formula from the prelab part 2b, which calculates the drop time for the horizontally fired projectiles, into your spreadsheet. Incorporate the muzzle height into the formula by reference.

##### ***Launch speed***

1. Enter the measured projectile ranges  $x$  from the horizontal launches (Activity 1) into the spreadsheet.
2. Calculate  $\bar{x}$ , the mean value of the projectile range (horizontal distance), incorporating the measurements by reference. (Sheets has an AVERAGE function.)
3. Enter the formula you found in the prelab part 3b in the spreadsheet. Incorporate the calculated value of  $\bar{x}$  by reference.

- This formula calculates  $v_x$ . Because the launches were horizontal in this activity, this is also your estimate of  $v_0$ .

### Activity 2. Measured range

- Enter the launch data into your spreadsheet. Organize it as a matrix, with a row for each angle and a column for each range.
- Add a column for the mean ranges. Calculate the mean range for each launch angle.

### Predicted ranges

- Below the data matrix, fill the angle column with angles from 0 to 65, with each row increased from the previous row by 1.
- In the next row, convert the degrees to radians. ( $180^\circ = \pi$  radians.)
- In the next two rows, calculate  $v_{0x}$  and  $v_{0y}$  for the angles. Use your estimate of  $v_0$  by reference.
- In the next row, calculate the time  $t$  that the projectile should be in the air. Use the formula from the prelab part 4c. Incorporate the values of  $h$  and  $v_{0y}$  by reference.
- In the next row, calculate the expected range for each projectile. Use the formula from the prelab part 3a. Incorporate the values of  $t$  and  $v_{0x}$  by reference.

### Plot

Make a plot of range  $x$  as a function of launch angle  $\alpha$ , containing your calculations for angles  $0^\circ$ – $65^\circ$  and the averages from the experimental angles. The experimental ranges should be shown as plot symbols with no line connecting them. The calculations would be best shown as a smooth curve without plot symbols, but if you can't figure out how to do that on the same plot with the bare plot symbols (I can't), show them as smaller plot symbols. Both  $x$  columns (experimental and calculated range) should use the same  $\alpha$  column. Make sure that the plot, the axes, and the two sets of  $x$  values are clearly labeled.

### Analysis

Do the measured and calculated ranges match reasonably well? If not, first check to see if you have made an error in a formula, calculation, or measurement. If you find errors, fix them. If you don't find errors, see me for help. If, after all this, the measured and calculated ranges still do not match, try to figure out what is wrong.

If the measured and calculated ranges match, estimate the angle  $\alpha$  giving the longest range.

### Lab Report

Turn in your completed **data sheet**.

Share your **spreadsheet** with me. Each student should have an individual, personal spreadsheet. It should be set up clearly and organized logically. Appropriate column headings and labels should lead me to the data, the intermediate calculations such as  $v_0$ , and the results. The spreadsheet should include your **plot** of predicted and measured  $x$  vs.  $\alpha$ .

**Analysis:** Comment on the match between the measured and predicted ranges. What does the match, or lack thereof, indicate about the model and the data? Tell me your estimate of the angle  $\alpha$  giving the longest projectile range.