# Two-Dimensional Motion: Projectiles

Structured

Driving Question | Objective

What is the range of a projectile launched horizontally? Develop a plan to measure the variables that affect the two-dimensional motion of a projectile launched horizontally, and then use those variables to accurately predict and test the projectile's horizontal range.

Materials and Equipment

|  |  |
| --- | --- |
| * Data collection system | * Steel ball, 1.6-cm diameter2 |
| * PASCO Wireless Smart Gate photogate1 | * Table clamp |
| * PASCO Mini Launcher2 | * White paper, 1 sheet |
| * PASCO Photogate Mounting Bracket2 | * Carbon paper, 1 sheet |
| * Mini launcher bracket2 | * Cardboard, square piece, 10 × 10 inch |
| * Launcher loading rod2 | * Meter stick |

|  |  |
| --- | --- |
| 1[www.pasco.com/ap38](http://www.pasco.com/ap38) | 2[www.pasco.com/ap05](http://www.pasco.com/ap05) |
|  |  |
| PASCO Wireless  Smart Gate | PASCO Mini Launcher |

Background

The motion of a projectile can be described using kinematics applied in both the vertical and horizontal directions. Assuming air resistance is negligible, a projectile launched horizontally only experiences acceleration in the vertical y direction, while its velocity in the horizontal x direction remains constant until the projectile strikes a target. Given this, the horizontal range ∆x for a projectile can be found using the following equation:

 (1)

where  is the initial horizontal velocity of the projectile and t is its time of flight. To find the time of flight t, the vertical motion of the projectile must be analyzed. Given that the initial height of the projectile is ∆y and the acceleration it experiences in the vertical direction is from gravity, the following kinematic equation can be used to isolate t:

 (2)

where a*y* is the acceleration due to gravity and  is the vertical component of the projectile's initial velocity. Assuming that the projectile's initial vertical velocity is zero, the first term drops out and Equation 2 can be rearranged to solve for t (substituting g for the acceleration in the vertical direction):

 (3)

Combining equations 1 and 3 produces the mathematical relationship between launch height ∆y and initial velocity for a free falling projectile launched horizontally:

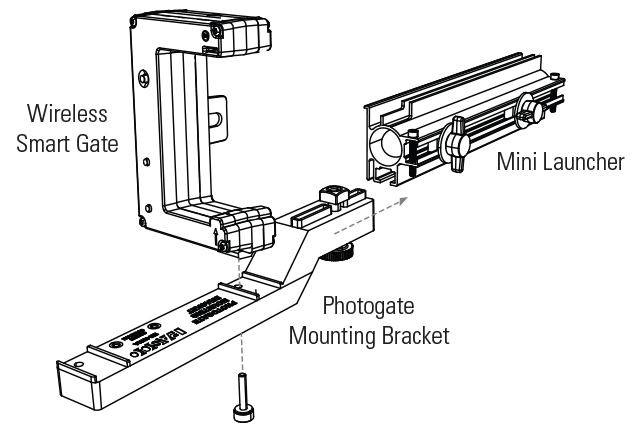
 (4)

Safety

Follow these important safety precautions in addition to your regular classroom procedures:

* Wear safety goggles at all times.
* Do not look into the launcher.
* Do not aim the launcher at others.
* Use only what the teacher provides as the plunger to load the projectile launcher.

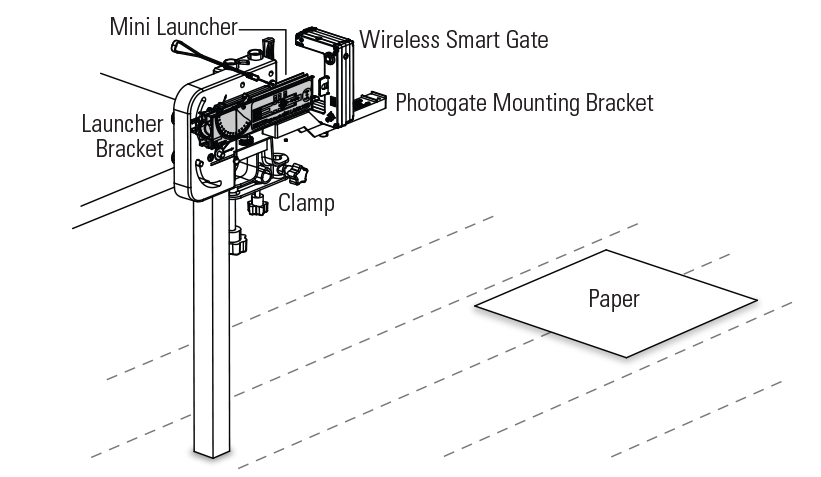
Procedure

Set Up

1. Connect the photogate mounting bracket and photogate to the mini launcher as in the figure to the right.

2. Choose one corner of a table to mount the projectile launcher. Make sure a distance of about 3 m is clear on the floor around the table in the direction you plan to launch the projectile.

3. Clamp the launcher to the corner of the table using the table clamp, and then adjust the angle of the mini launcher to zero degrees   
(horizontal launch).



4. Connect the photogate to the data collection system.

5. Configure the data collection system to use the photogate timing to measure the initial speed of the projectile passing through the photogate, and then display this measurement in a digits display.

Collect Data

6. Measure the height of the point the projectile will exit the launcher relative to the floor. Record this value in the Data Analysis section below.

7. Place the steel ball into the launcher, and use the push rod or plunger to load the ball as far into the launcher as possible (three clicks).

8. Hold a piece of cardboard a few centimeters past the photogate to block the ball.

9. Start recording data, and then pull up on the cord attached to the trigger to launch the ball. Make sure it strikes the cardboard before it lands on the ground.

10. Stop data recording.

11. Record the initial speed of the projectile in Table 1 in the Data Analysis section.

12. Repeat the data collection steps 4 additional times. Record the initial speed of the projectile for each trial into Table 1.

Data Analysis

|  |  |
| --- | --- |
| Height of launcher at projectile exit point (m): |  |

Table 1: Initial velocity of projectile launched horizontally

|  |  |
| --- | --- |
| Trial | Initial Velocity (m/s) |
| 1 |  |
| 2 |  |
| 3 |  |
| 4 |  |
| 5 |  |
| Ave Velocity (m/s) |  |

1. Calculate the projectile’s average initial velocity and record your result into Table 1.

Calculate the Range

2. Using your average launch velocity and the measured height of the launcher, calculate the range of the projectile using the equation:

 (4)

For your calculation assume that g = 9.81 m/s2. Show your work here:

Test the Range

3. Draw a circle with a radius of 8 cm in the center of a piece of white paper, and then tape the paper to the floor in front of the projectile launcher with the center of the circle at a distance equal to your predicted range.

4. Place carbon paper over the white paper, and then align the projectile launcher with the center of the paper.

5. Place the steel ball into the launcher and then use the push rod or plunger to load the ball as far into the launcher as possible (three clicks).

6. Launch the ball toward the paper. Place the steel ball back into the launcher and repeat the test four more times.

7. Remove the carbon paper. Observe the locations where the ball struck the paper.

Analysis Questions

* 1. Assuming air resistance is negligible, what other variables affect the range of a projectile?

* 2 Qualitatively describe how close your predicted range is to your actual range in terms of accuracy (the relative distance between each test shot and the actual target) and precision (the grouping of the test shots). Use the tables below to help.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Accuracy | Accuracy Definition |  | Precision | Precision Definition |
| Very high | All shots in 8 cm target |  | Very high | All shots within 3 cm radius |
| High | Four shots in 8 cm target |  | High | Four shots within 5 cm radius |
| Moderate | Three shots in 8 cm target |  | Moderate | Two shots within 8 cm radius |
| Low | Two shots in 8 cm target |  | Low | Two shots within 20 cm radius |
| Very low | One or no shots in 8 cm target |  | Very low | No shots within 30 cm radius |

* 3. What are factors that may have caused your range prediction to be incorrect, and what could you have done differently to avoid them?

* 4. Sketch the complete trajectory of your projectile. Draw your projectile at five locations on its trajectory (evenly spaced). At each of these locations, draw the net force vector acting on the projectile at that location. Make sure the lengths of the vectors represent the relative magnitudes.
* 5. Sketch the complete trajectory of your projectile. Redraw the projectile at the same five locations used in the previous question. At each of these locations, draw the projectile’s horizontal and vertical component velocity vectors. Make sure the lengths of the vectors represent the relative magnitudes of the velocities.
* 6. How did the kinetic energy of the projectile change in its trajectory? Use your sketches from the previous questions to explain how the kinetic energy of the projectile changed in its trajectory.

Synthesis Questions

* 1. A ball player throws a ball horizontally. What variables affect the horizontal range of the ball?

* 2. For the same ball player, how would doubling the initial velocity affect the range, if at all?

* 3. For the same ball player, how would quadrupling the height affect the range, if at all?

* 4. For the same ball player, how would doubling the mass of the ball affect the range, if at all?