Mini Launcher

ME-6825B

Introduction

The Mini Launcher has been designed for projectile experiments and demonstrations. The only additional equipment required is a C-clamp for securing the stand to a table, or a Large Table Clamp (ME-9472) and support rod for mounting the launcher with the built-in rod clamp. The launcher can be mounted so that the barrel pivots at the muzzle end, so that the elevation of the ball as it leaves the barrel does not change when the angle is varied.

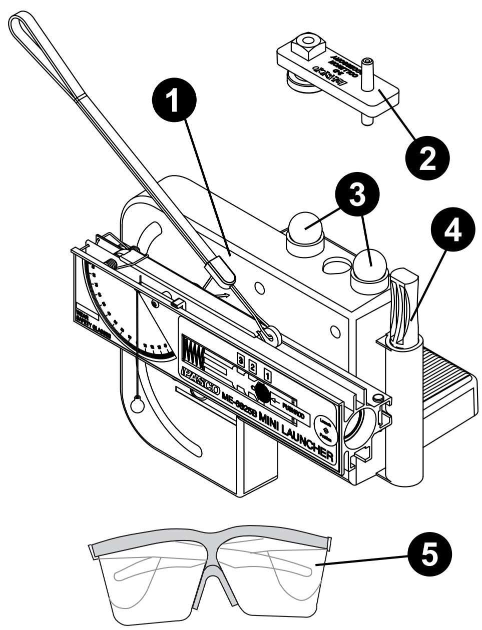
The steel ball projectile can be launched at any angle from 45° below the horizontal to 90° above the horizontal. The magnetic piston holds the ball in position for launch at an angle from 0° to 45° below the horizontal. This angle can be easily adjusted using the thumbscrews. The built-in protractor and metal plumb bob on the side of the launcher can be used to determine the angle of inclination.

The ball is launched with no spin, since the piston prevents the ball from rubbing against the walls as it travels up the barrel. Securing the sturdy base to a table will ensure the shot produces very little recoil. The trigger is pulled with a lanyard to minimize jerking.

A Photogate Mounting Bracket (ME-6821A) may be used to attach photogates to the Mini Launcher, allowing you to measure the muzzle speed. You can also use the launcher with a Time-of-Flight Accessory (ME-6810A) and a photogate to measure a projectile's time of flight.

Equipment

Included equipment:



1. Mini Launcher
2. 2D Collision Accessory
3. 2× steel balls, 16 mm
4. Pushrod
5. Safety glasses

Recommended items:

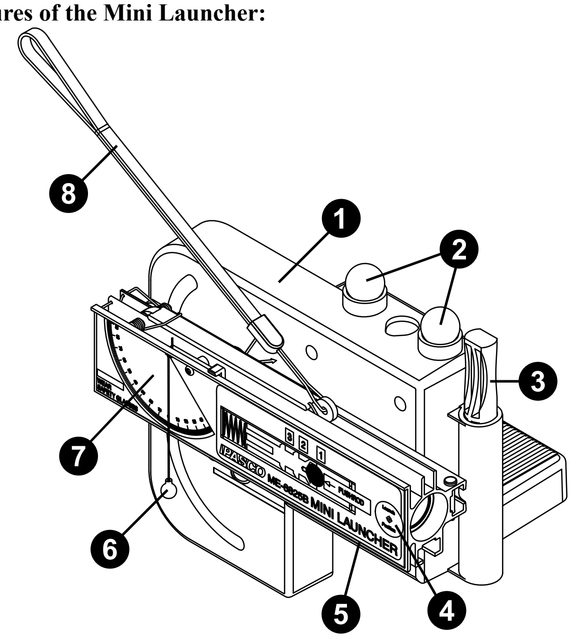
- Stainless Steel Rod, 45 cm (ME-8736)
- Large Table Clamp (ME-9472)
- Replacement Plumb Bobs (12 Pack) (ME-9868)
- Large C Clamp (6 Pack) (SE-7285)
- Carbon Paper, 100 Sheets (SE-8693)
- Plumb Bobs, 10 Pack (SE-8728)

Other compatible items:

- Wireless Smart Gate (PS-3225), Smart Gate (PS-2180), or Photogate Head (ME-9498A)
- Photogate Mounting Bracket (ME-6821A)
- Time-of-Flight Accessory (ME-6810A)
- Mini Ballistic Pendulum Accessory (ME-6829)

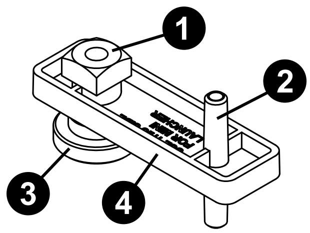
Features

Features of the Mini Launcher:



1. Mini Launcher stand
2. Steel balls
3. Pushrod
4. Launch position of ball
5. Mini Launcher
6. Plumb bob
7. Protractor
8. Lanyard

Features of the 2D Collision Accessory:

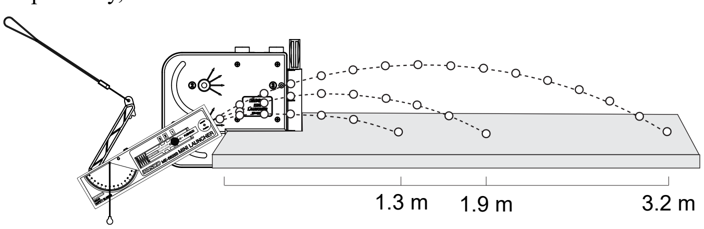


1. Square nut
2. Post
3. Thumbscrew
4. Plastic piece

Usage

About the Mini Launcher

The Mini Launcher features three ranges for its fired projectiles, labeled positions 1, 2, and 3. The range of a projectile is determined by the position setting of the piston (see **Loading**). When the Mini Launcher is tilted at an angle of 45° and fired from table top to table top, positions 1, 2, and 3 will yield ranges of approximately 1.3 m, 1.9 m, and 3.2 m respectively, as shown below.



When using the Mini Launcher, keep in mind:

- The muzzle speed will vary slightly with angle. Depending on the range setting and the particular launcher, the muzzle speed may differ by up to 8% across its range of angles.
- To minimize the scatter pattern, securely clamp the Mini Launcher stand to a sturdy table. Any wobble in the table will affect the data.
- The protractor allows you to determine the angle of inclination to within 0.5°.

Setup

Always wear safety goggles when you are in a room where the Mini Launcher is being used. A pair of safety glasses are provided with the Mini Launcher for this purpose.

> ⚠ **CAUTION:** Never look down the front of the barrel, as it may be loaded and trigger by accident. Always assume the Mini Launcher is loaded!

The Mini Launcher stand can be fastened to the edge of a table using a clamp of your choice. To secure the Mini Launcher to the stand, align the square nut closer to the barrel with one of the pivot holes, insert and tighten one of the included thumbscrews into this square nut via the pivot hole, then insert the other thumbscrew into the other square nut via the adjacent curved slot. See **Launch position examples** for more information and mounting options.

When shooting onto the floor, mount the launcher so that the muzzle is even with or slightly beyond the end of the table. This will allow you to use a plumb bob to locate the point on the floor directly below the muzzle. The Mini Launcher can also be mounted to shoot onto a table so that the launch position of the ball is at the same height as the landing position on the table. To prevent the steel ball from denting the floor or tabletop, you may want to place a protective covering on the surface.

Aiming

To adjust the angle of inclination, loosen the thumbscrews on the back of the stand, then rotate the barrel of the Mini Launcher to the desired angle above or below the horizontal, as indicated by the plumb bob and protractor on the side. (See **Launch position examples** for more information.) When the Launcher is at the desired angle, tighten the thumbscrews to secure it in place.

Loading

> **NOTE:** Only cock the Launcher when a ball is in the piston; using the pushrod without a ball in the piston may cause damage to the Launcher. Only use 16 mm steel balls with the Mini Launcher.

1. Insert a 16 mm steel ball into the barrel.
2. Push the ball down the barrel with the pushrod until the trigger catches a notch on the piston. Listen for a number of clicks equal to your desired setting:
    - One audible click indicates that the trigger is holding at position 1, the shortest range setting.
    - Two clicks indicate that the piston is cocked at position 2, the medium range setting.
    - Three clicks indicate that the piston is cocked at position 3, the long range setting.
3. Remove the pushrod and return it to its holder on the stand.

> ⚠ **CAUTION:** Do not push a ball down the barrel with your finger. Your knuckle may get stuck.

Shooting

Before launching the ball, make certain that no person is in the way. To shoot the ball, pull upward on the lanyard by about a centimeter to release the trigger. The position of the ball when it leaves the barrel is indicated by the circular marking adjacent to the muzzle. When measuring the vertical distance the ball drops, measure from the floor to the bottom of this launch position marker.

Storage

Always store the Mini Launcher with the spring uncompressed. Do not store the launcher in a cocked position.

Installing accessories

Photogate Mounting Bracket

The Photogate Mounting Bracket (ME-6821A) is an optional accessory for mounting a Smart Gate (PS-2180), Wireless Smart Gate (PS-3225), or one or two Photogate Heads (ME-9498A) on the front of the Mini Launcher. When these gates are mounted in this way and connected to PASCO data collection software, you can use them to determine the muzzle velocity of the ball. To install the Photogate Mounting Bracket and photogates:

1. Loosen the thumbscrew near the end of the Photogate Mounting Bracket that holds the square nut.
2. To attach a Smart Gate, Wireless Smart Gate, or Photogate Head to the bracket, place the gate between the alignment ridges near the square nut, then insert a small thumbscrew into the hole from below and tighten to secure in place. (*Optional:* If you are using a second Photogate Head, attach it to the other end of the bracket in the same way.)
3. Align the square nut with the T-slot on the bottom of the Mini Launcher's barrel, then slide the nut into the slot, as shown in Figure 1.
4. Align the bracket on the Mini Launcher so that the Smart Gate, Wireless Smart Gate, or first Photogate Head is as close to the barrel as possible without blocking the infrared beam. Tighten the thumbscrew to secure the bracket in place.

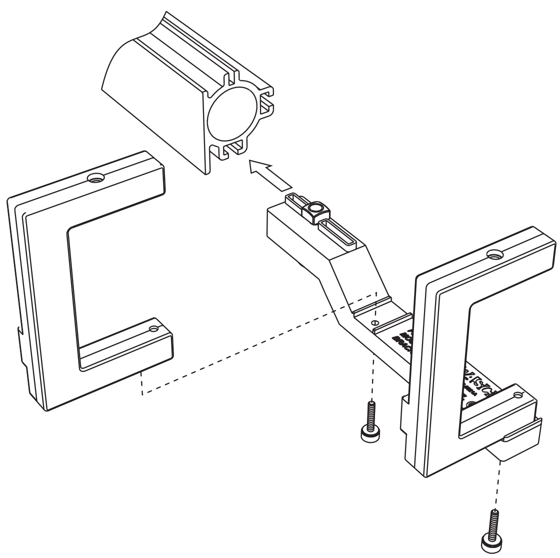


Figure 1: Mounting the Photogate Mounting Bracket and photogates.

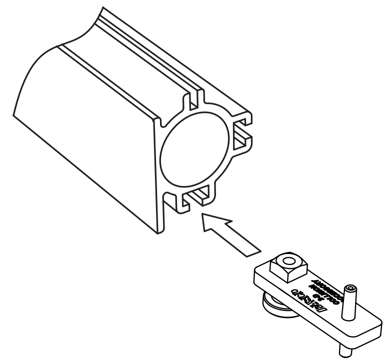
> **NOTE:** When storing the Mini Launcher, you do not need to remove the Photogate Mounting Bracket. Slide the bracket back along the barrel with or without photogates in place to make the package as compact as possible.

2D Collision Accessory

The 2D Collision Accessory consists of a thumbscrew, a square nut, and a molded plastic piece. The plastic piece has text on both sides, with one side reading "PASCO 2-D COLLISION ACCESSORY" and the other reading "USE THIS SIDE FOR MINI LAUNCHER". This accessory can be used with any PASCO projectile launcher.

To assemble and mount the accessory:

1. Orient the plastic piece with the "USE THIS SIDE FOR MINI LAUNCHER" side facing upward.
2. Insert the thumbscrew through the hole in the bottom of the piece, then insert the square nut onto the thumbscrew. Leave the nut slightly loose for now.
3. Align the square nut with the T-slot on the bottom of the Mini Launcher barrel, then slide the nut into the slot as shown below and tighten the thumbscrew to secure the accessory in place.



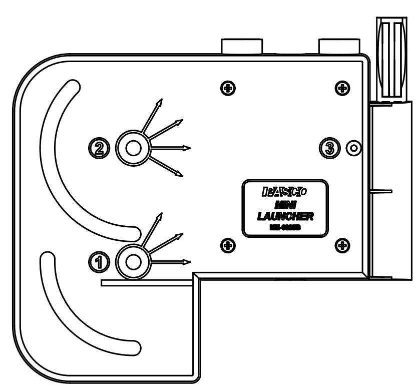
To use the accessory, place a ball on top of the post so that it is struck by the ball fired from the barrel. Slightly loosen the thumbscrew, then rotate the accessory to one side or the other until the ball on the post will be struck at the desired angle without causing the launched ball to bounce back against the barrel.

Launch position examples

The Mini Launcher can be attached to the stand in more than one way. The square nuts in the T-slot on the side of the barrel can slide from end to end of the T-slot. The plastic divider in the T-slot between the square nuts keeps the nuts in proper position relative to each other.

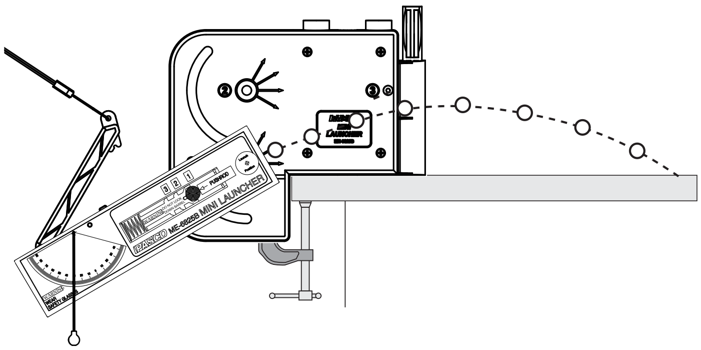
As shown in the diagram below, the stand features a lower pivot hole marked as ❶ and an upper pivot hole marked as ❷, each of which is adjacent to a curved slot. The upper curved slot allows the Mini Launcher to shoot the ball at an angle from -45° to 90° with respect to the horizontal plane. The lower curved slot allows the Launcher to shoot at an angle from 0° to 90°.

At the same height as the upper pivot hole is an alignment tab, located at the front edge of the stand and marked as ❸. When the barrel is mounted in the upper position, the muzzle end of the T-slot on the side of the Mini Launcher barrel can slide forward to fit over the alignment tab. This will ensure the Launcher stays fixed at an angle of 0°, preventing it from shifting for experiments where a purely horizontal launch is required.

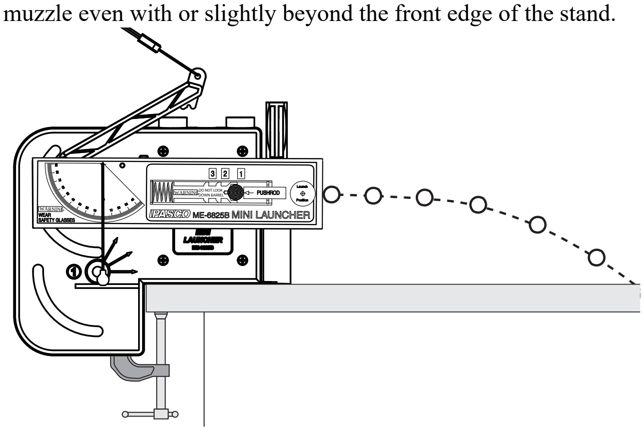


The illustrations below show some examples of ways in which the Mini Launcher can be mounted on the stand for experiments.

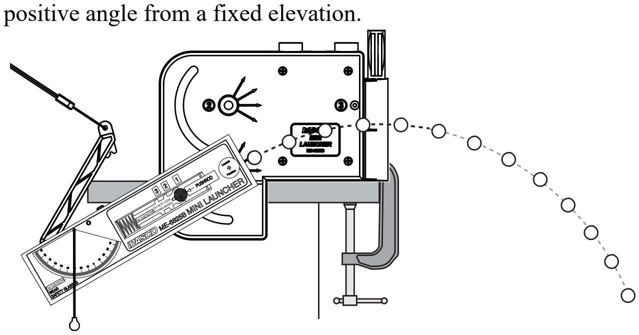
- **Example 1:** Clamp the Mini Launcher stand to a table and mount the barrel in the lower position, with the muzzle aligned with the pivot hole (marked ❶), as shown below. The Mini Launcher will be able to shoot onto the table from the same level as the table. The ball is launched with a positive angle at table elevation. When you change the angle of the launcher, the elevation of the launch position does not change.



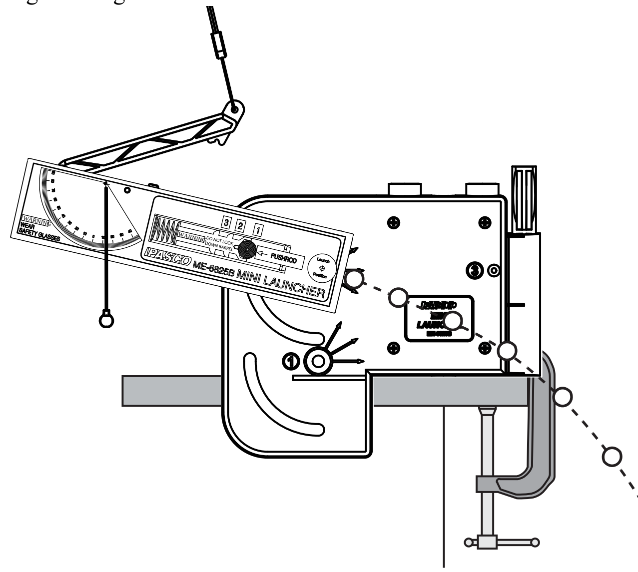
- **Example 2:** Clamp the Mini Launcher stand to a table and mount the barrel in the upper position using the upper pivot hole (marked ❷). Slide the barrel forward so that the T-slot on the side of the Launcher fits over the alignment tab (marked ❸). In this position, the launch angle is always 0° and the ball will always be shot horizontally from a constant height. When using the Mini Launcher Ballistic Pendulum Accessory (ME-6829), put the muzzle even with or slightly beyond the front edge of the stand.



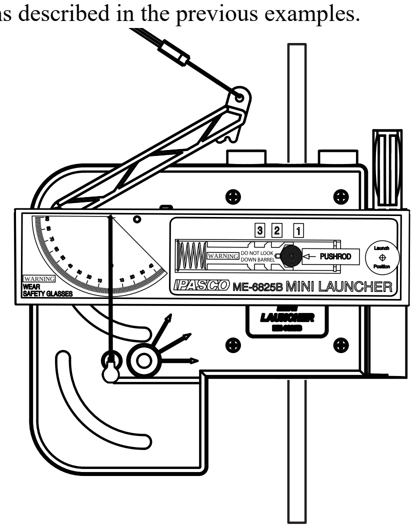
- **Example 3A:** Clamp the Mini Launcher stand to the side edge of a table near the corner, then mount the Mini Launcher in the lower position. This allows you to shoot from the table onto the floor at a positive angle from a fixed elevation.



- **Example 3B:** Clamp the Mini Launcher base to the side edge of a table near the corner, then mount the Mini Launcher in the upper position. This allows you to shoot from the table onto the floor at a negative angle from a fixed elevation.



- **Example 4:** Mount the Mini Launcher stand on a vertical support rod. From here, the barrel can be mounted on the stand in any of the positions described in the previous examples.



Experiment 1: Projectile Motion

Required equipment

- Mini Launcher and ball
- Plumb bob and string
- Meter stick
- Carbon paper
- White paper
- Tape

Purpose

The purpose of this experiment is to predict and verify the range of a ball launched at an angle. The initial speed of the ball is determined by shooting it horizontally and measuring the range of the ball and the height of the Mini Launcher's muzzle.

Theory

To predict where a ball will land on the floor when it is shot from the Launcher at some angle above the horizontal, you will first need to determine the initial speed (muzzle velocity) of the ball. This speed can be determined by shooting the ball horizontally from the Mini Launcher and measuring the vertical and horizontal distances that the ball travels. This initial speed can then be used to calculate where the ball will land when fired at an angle above the horizontal.

Firing Horizontally

For a ball shot horizontally from a table with an initial speed v_0, the horizontal distance x traveled by the ball is given by $x = v_0 t$, where t is the time the ball is in the air. (For this experiment, we will ignore air resistance.) In this same time t, the ball drops a vertical distance y, as given by:

$$y = \tfrac{1}{2} g t^2$$

The initial speed v_0 can be determined by measuring x and y. The time of flight t can be found by solving the previous equation to obtain:

$$t = \sqrt{\frac{2y}{g}}$$

From this, the initial horizontal speed, which is equivalent to the muzzle velocity of the ball, is given by:

$$v_0 = \tfrac{x}{t}$$

Firing At an Angle

To predict the horizontal range x of a ball shot with initial velocity v_0 at an angle θ above the horizontal, you will first need to predict the time of flight. You can do so using the equation for the vertical motion:

$$y = y_0 + (v_0 \sin\theta)t - \tfrac{1}{2} g t^2$$

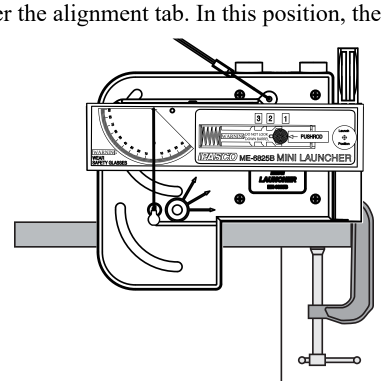
where y_0 is the initial height of the ball and y is the position of the ball when it hits the floor. Since $y = 0$ when the ball strikes the floor, you can find t by solving the quadratic equation. From there, calculate x using the equation:

$$x = v_0 \cos\theta \; t$$

where $v_0 \cos\theta$ is the horizontal component of the initial speed.

Setup

Clamp the Mini Launcher stand near the corner of a sturdy table so that the Launcher will be aimed away from the table. Mount the Mini Launcher in the upper position, with the T-slot at the muzzle end over the alignment tab. In this position, the ball will always be launched horizontally.



Procedure

Part 1: Determining the ball's initial horizontal speed

1. Put a ball into the Mini Launcher and use the pushrod to cock it at the long range position.
2. Fire one shot to locate where the ball hits the floor. At that point, tape a piece of white paper to the floor, then place a piece of carbon paper carbon-side-down on top of the white paper and tape it in place. When future shots hit the floor here, a mark will be left on the white paper.
3. Repeat Step 1 ten times.
4. Measure the vertical distance from the bottom of the ball as it leaves the barrel to the floor. Record this distance in the blank above Table 1.1.
5. Use a plumb bob to find the point on the floor that is directly beneath the launch position (as marked on the barrel). Measure the horizontal distance along the floor from this point to the leading edge of the piece of white paper. Record this distance in the blank above Table 1.1.
6. Carefully remove the carbon paper and measure from the leading edge of the white paper to each of the ten dots. Record these distances in Table 1.1, then calculate the average distance and record this as well.
7. Calculate the total horizontal distance (the distance to the paper plus the average distance from the edge of the paper to the dots). Record this value in Table 1.1.
8. Using the vertical distance y and the total horizontal distance x, calculate the time of flight t and the initial horizontal speed of the ball v_0. Record these values in the blanks below Table 1.1.

Vertical distance = _______________

Horizontal distance to edge of paper = _______________

Figure 1.1: Data from Part 1

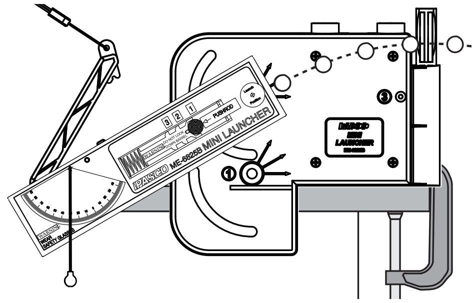
Trial	Distance
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Total distance	

Calculated time of flight t = _______________

Initial speed v_0 = _______________

Part 2: Predicting the range of a ball shot at an angle

1. Slide the barrel as far back as possible so that the barrel stays at a fixed height, then adjust the angle of the Mini Launcher to between 30° and 60°. Record this angle in the blank above Table 1.2.



2. Using the initial speed and vertical distance from Part 1, calculate the new time of flight *t* and the new horizontal distance assuming the ball is shot at the angle you just selected. Record these predictions in the blanks above Table 1.2.
3. Draw a line across the middle of a white piece of paper, then tape the paper on the floor so that the line on the paper is at the predicted horizontal distance from the Mini Launcher. Cover the white paper with carbon paper (carbon side down) and tape the carbon paper in place as well.
4. Fire the ball ten times.
5. Carefully remove the carbon paper. Measure the distances to the ten dots and record these distances in Table 1.2.
6. Take the average of these ten distances, then record the average in Table 1.2.
7. Calculate the total horizontal distance (the distance to the paper plus the average distance from the edge of the paper to the dots). Record this value in Table 1.2.

Angle above horizontal = _______________; Horizontal distance to edge of paper = _______________

Calculated time of flight t = _______________; Predicted range x = _______________

Figure 1.2: Data from Part 2

Trial	Distance
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Total distance	

Analysis

1. Calculate the percent error between the predicted theoretical distance and the actual average distance when shot at an angle. This percent error is given by the equation:

$$\frac{|\,\text{theoretical} - \text{actual}\,|}{\text{theoretical}} \times 100\%$$

2. Estimate the precision of the predicted range. How many of the final 10 shots landed within this range?

Experiment 2: Projectile Motion with Photogates

Required equipment

- Mini Launcher and ball
- Plumb bob and string
- Photogate Mounting Bracket (ME-6821A)
- Any of the following combinations of components:
  - Wireless Smart Gate (PS-3225)
  - Smart Gate (PS-2180) and any PASPORT interface
  - 2× Photogate Heads (ME-9498A) and a PASCO analog interface
- PASCO Capstone or SPARKvue data collection software, *or* Smart Timer (ME-8930; only compatible with Photogate Heads)
- Meter stick
- Carbon paper
- White paper
- Tape

Purpose

The purpose of this experiment is to predict and measure the range of a ball launched at an angle. Photogates are used to find the ball's initial speed.

Theory

To predict where a ball will land on the floor when it is shot from the Mini Launcher at some angle above the horizontal, you first need to determine the initial speed (muzzle velocity) of the ball. Rather than calculating this value, you can measure it directly by shooting the ball and measuring an interval using photogates.

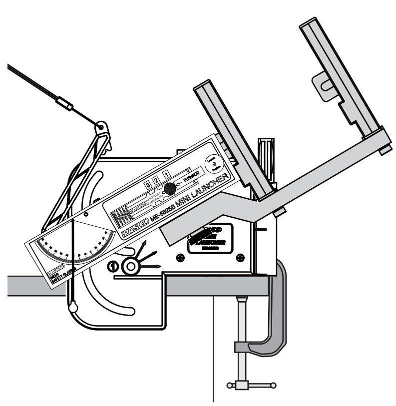
To predict the horizontal range x of a ball shot with initial velocity v_0 at an angle θ above the horizontal, you will first need to predict the time of flight. You can do so using the equation for the vertical motion:

$$y = y_0 + (v_0 \sin\theta)t - \tfrac{1}{2}gt^2$$

where y_0 is the initial height of the ball and y is the position of the ball when it hits the floor. Since $y = 0$ when the ball strikes the floor, you can solve the quadratic equation for t and then calculate x using the equation $x = v_0\cos\theta\ t$, where $v_0\cos\theta$ is the horizontal component of the initial speed.

Setup

1. Clamp the Mini Launcher to one end of a sturdy table or other horizontal surface. Mount the Mini Launcher so that it points off the table, as shown in the illustration.
2. Adjust the angle of the Mini Launcher to an angle between 30° and 60°. Record this angle.
3. Attach the Photogate Mounting Bracket to the Mini Launcher, then attach a Smart Gate, Wireless Smart Gate, or two Photogate Heads to the bracket. If you are using Photogate Heads, make sure the distance between the photogates is 0.10 m (10 cm).
4. Connect the Smart Gate, Wireless Smart Gate, or Photogate Heads to PASCO Capstone or SPARKvue. If you are using a Smart Timer instead, plug the Photogate Heads into the timer.



Procedure

Part 1: Determine the initial speed of the ball

1. Put a ball in the Mini Launcher and use the pushrod to cock it at the long range position.
2. Set up the software to measure the time between the ball blocking the two beams of the Smart Gate or Wireless Smart Gate or the two Photogate Heads. (If you are instead using a Smart Timer, set up a timer to measure the time between the ball blocking the two Photogate Heads.) For more information on this, see the manual for the chosen apparatuses and the PASCO Capstone or SPARKvue online help.
3. Shoot the ball three times. For each run, record the time between the gates being blocked, as reported by the program, in Table 2.1.
4. Take the average of the time values from the three runs. Record this average in Table 2.1.
5. Calculate the initial speed of the ball using the average time and the distance between the two photogate beams. Record this value in the blank below Table 2.1.

Table 2.1: Data from Part 1

Trial	Time
1	
2	
3	
Average time	

Initial speed v_0 = ________________

Part 2: Predict the range of a ball shot at an angle

NOTE: Keep the angle of the Mini Launcher at the same angle above the horizontal as in Part 1.

1. Measure the vertical distance from the bottom of the ball as it leaves the barrel to the floor. (You can use the "Launch Position" marking on the side of the barrel to aid in measurement.) Record this value in the blank below.
2. Using the vertical distance, the angle, and the initial speed, solve the equation of vertical motion in the **Theory** section for the time of flight t. Record this value in the blank below.
3. Use the time of flight t, angle θ, and initial speed v_0 to predict the horizontal distance, using the equation

$$x = (v_0 \cos\theta)t$$

   Record this prediction in the blank below.

4. Draw a line across the middle of a white piece of paper, then tape the paper on the floor so that the line is at the predicted horizontal distance. Cover the white paper with carbon paper, with the carbon side down, and tape the carbon paper in place.
5. Use a plumb bob to find the point on the floor directly below the launch position, as marked on the barrel. Measure the horizontal distance along the floor from this point to the leading edge of the white paper. Record this distance in the blank below.
6. Shoot the ball ten times.
7. Carefully remove the carbon paper and measure the distance from the leading edge of the white paper to each of the ten dots. Record these distances in Table 2.2.
8. Find the average of the ten distance values from the previous step. Record this average in Table 2.2.
9. Add up the distance to the edge of the paper and the average distance you calculated in the last step to obtain the total horizontal distance. Record this total distance in Table 2.2.

Angle above horizontal = ________________

Horizontal distance to edge of paper = ________________

Calculated time of flight = ________________

Predicted range = ________________

Table 2.2: Data from Part 2

Trial	Distance
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Total distance	

Analysis

1. Calculate the percent error between the predicted theoretical distance and the actual average distance when shot at an angle. The percent error is given by the equation:

$$\frac{|\,\text{theoretical} - \text{actual}\,|}{\text{theoretical}} \times 100\%$$

2. Estimate the precision of the predicted range. How many of the final 10 shots landed within this range?

Experiment 3: Projectile Range versus Angle

Required equipment

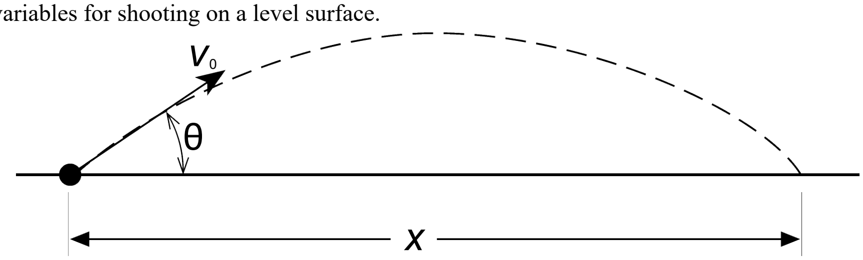
- Mini Launcher and ball
- Plumb bob and string
- Meter stick or measuring tape
- Graph paper
- White paper
- Carbon paper

Purpose

The purpose of this experiment is to determine how the range of the ball depends on the launch angle. The angle that gives the greatest range is determined for two cases: shooting on level ground, and shooting off a table.

Theory

The *range* is the horizontal distance *x* between the muzzle of the Launcher and the place where the projectile strikes the ground. This value is given by $x = (v_0 \cos\theta)t$, where v_0 is the initial speed (muzzle velocity) of the projectile, θ is the launch angle above the horizontal, and *t* is the time of flight. The image below illustrates these variables for shooting on a level surface.



If the projectile impacts a surface on the same level as the muzzle of the launcher, the time of flight of the projectile will be exactly twice the time it takes for the projectile to reach the peak of its trajectory. At the peak, the vertical speed is zero, so setting v_y to 0, we find that:

$$v_y = 0 = (v_0 \sin\theta) - g t_{\text{peak}}$$

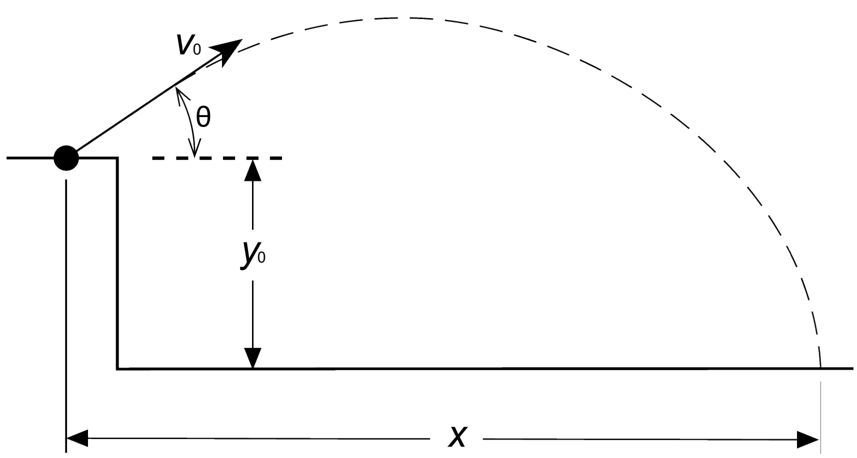
Solving this for t_{peak}, the time required to reach the peak, we can determine that the total time of flight is given by:

$$t = 2t_{\text{peak}} = 2\left(\frac{v_0 \sin\theta}{g}\right)$$

For cases where the projectile is launched at an angle above the horizontal from a table onto the floor, the time of flight is instead found using the equation for vertical motion:

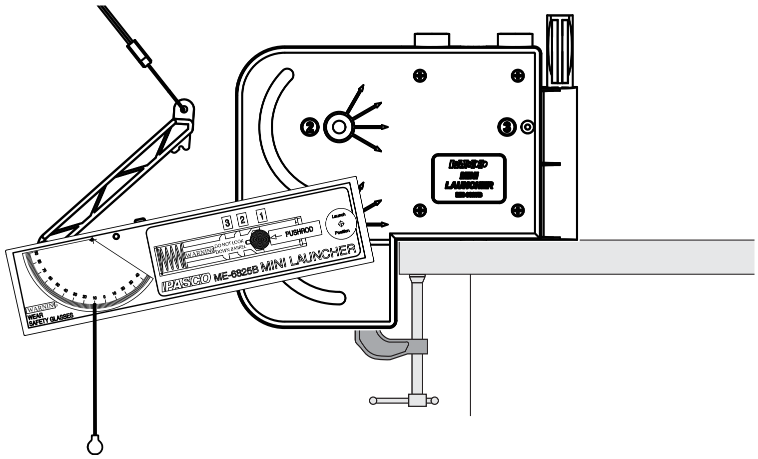
$$y = y_0 + (v_0 \sin\theta)t - \tfrac{1}{2}gt^2$$

where y_0 is the initial height of the projectile in the Launcher and *y* is the vertical position of the ball after time *t*. The diagram below shows the relevant variables for shooting from a level surface to the floor.



Setup

1. Clamp the Mini Launcher stand to a sturdy table or other horizontal surface so that it is aimed toward the center of the surface, as shown below.
2. Mount the barrel in the lower position on the stand, then align the muzzle with the lower pivot hole. Adjust the angle of the Mini Launcher to 10° above the horizontal.
3. Place a ball into the Mini Launcher and cock it to the medium or long range setting. (The experiment will generally not work with the short range setting, since the muzzle speed at this setting is more variable with the change in angle.)



Procedure

Part 1: Shooting to a level surface

1. Fire one shot to locate where the ball hits the table. Tape a piece of white paper on the table at this location, then tape a piece of carbon paper, with the carbon side down, on top of the white paper. When the ball hits the carbon paper, it will leave a mark on the white paper underneath.
2. Fire five shots.
3. Use a plumb bob to locate the point on the table directly beneath the launch position, as marked on the side of the barrel. Using a measuring tape, measure the horizontal distance from this point to the leading edge of the paper. Record this value under **Paper distance** in Table 3.1.
4. Carefully remove the carbon paper, then measure the distance from the leading edge of the paper to each of the five dots. Record these distances in Table 3.1.
5. Increase the launch angle by 10 degrees, then repeat Steps 1 through 4. Keep the muzzle at the same elevation.
6. Repeat Step 5 for all angles listed in Table 3.1.

Table 3.1: Data from Part 1

	10°	20°	30°	40°	50°	60°	70°	80°
Shot 1								
Shot 2								
Shot 3								
Shot 4								
Shot 5								
Average								
Paper distance								
Total distance								

Part 2: Shooting off the table

1. Re-position the Mini Launcher and stand so that the ball will be launched onto the floor.
2. Repeat the procedure from Part 1, recording the data in Table 3.2.

Table 3.2: Data from Part 2

	10°	20°	30°	40°	50°	60°	70°	80°
Shot 1								
Shot 2								
Shot 3								
Shot 4								
Shot 5								
Average								
Paper distance								
Total distance								

Analysis

1. Find the average of the five distances in each case. Record the results in Tables 3.1 and 3.2.
2. Add the average distance to the distance from the Mini Launcher to the leading edge of the white paper to obtain the total distance (range) in each case. Record the results in Tables 3.1 and 3.2.
3. For each data table, plot the range versus the angle and draw a smooth curve through the points.

Questions

1. From the graphs, what angle gives the maximum range for each case?
2. Is the angle for the maximum range greater or less for shooting off the table than for shooting on a level surface?
3. Is the maximum range further when the ball is shot off the table or on the level surface?

Experiment 4: Projectile Path

Required equipment

- Mini Launcher and ball
- Movable vertical target board

> **NOTE:** This board should be as tall as the distance from the muzzle to the floor.

- Meter stick or measuring tape
- Tape
- Graph paper
- Carbon paper
- White paper

Purpose

The purpose of this experiment is to determine how the vertical distance a projectile drops is related to the horizontal distance the projectile travels when the projectile is launched horizontally.

Theory

The *range* is the horizontal distance x between the muzzle of the Mini Launcher and the place where the projectile hits. This value is given by the equation $x = v_0 t$, where v_0 is the initial speed of the projectile as it leaves the muzzle and t is the time of flight.

If the projectile is launched horizontally, the time of flight of the projectile will be given by:

$$t = \frac{x}{v_0}$$

The vertical distance y that the projectile falls during this time is given by:

$$y = \frac{1}{2}gt^2$$

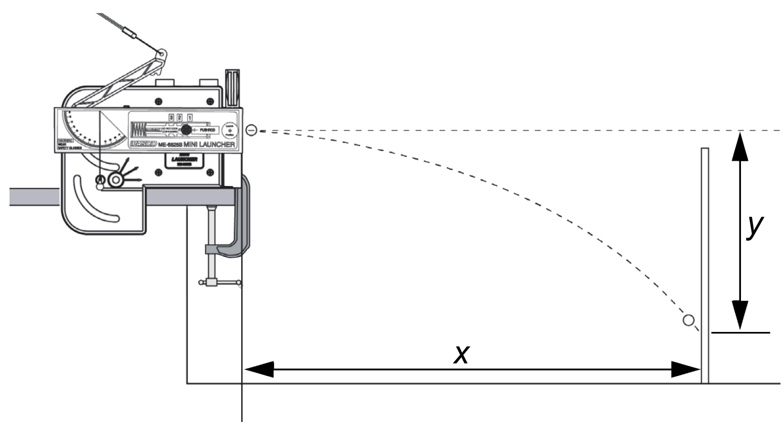
where g is the acceleration due to gravity. Substituting the first equation into the second, we find that:

$$y = \frac{1}{2}g\left(\frac{x}{v_0}\right)^2 = \left(\frac{g}{2v_0^2}\right)x^2$$

Therefore, a plot of y versus x^2 will yield a straight line with a slope equal to $\frac{g}{2v_0^2}$.

Setup

1. Clamp the Mini Launcher stand near the corner of a sturdy table. Mount the Launcher so it is aimed away from the table.
2. Adjust the angle of the Mini Launcher to 0° and slide the barrel over the alignment tab, ensuring the ball will be launched horizontally.
3. Fire a test shot on medium range to determine the initial position for the vertical target board. Place the target board at a position where the ball will hit the board near the bottom.
4. Cover the target board with white paper, then tape carbon paper over the white paper with the carbon side facing the white paper.



Procedure

1. Measure the vertical height from the floor to the bottom of the muzzle. Record this height in the space above Table 4.1.
2. Using a plumb bob, find the point on the floor directly beneath the launch position (as marked on the side of the barrel). Measure the horizontal distance between this point and the target board and record it in Table 4.1.
3. Shoot the ball once.
4. Move the target board about 10 to 20 cm closer to the Mini Launcher.
5. Repeat Steps 2 through 4 until the height of the ball when it strikes the target board is about 10 to 20 cm below the height of the muzzle.

Height of muzzle = _______________

Table 4.1

Horizontal distance (x)	Vertical distance (y)	x^2

Analysis

1. Carefully remove the carbon paper from the target board, then measure the vertical distances from the muzzle level mark down to each ball mark. Record these values in Table 4.1 on the row for the corresponding position.
2. Calculate x^2 for all of the distances. Record these values in Table 4.1.
3. Plot a graph of y versus x^2 and draw a best fit line through the data points.
4. Calculate the slope of the graph and record it in Table 4.2.
5. From the slope of the graph, calculate the initial speed of the ball as it leaves the muzzle. Record this initial speed in Table 4.2.
6. Pick any x, y data point from Table 4.1. Use the vertical distance y to calculate the time of flight t, then calculate the initial speed using the time t and the horizontal distance x. Record the time of flight and calculated speed in Table 4.2.
7. Calculate the percent difference between the two initial speeds that were found using the different methods. Record this percent difference in Table 4.2. To calculate the percent difference, let A be one of the initial speed values and B be the other initial speed value, then use the equation:

$$\left|\frac{A-B}{\left(\frac{A+B}{2}\right)}\right| \times 100\%$$

Table 4.2

Item	Value
Slope of graph	
Initial speed from slope	
Time of flight	
Initial speed from x, y	
Percent difference	

Questions

1. From the graph, was the best fit line straight?
2. What does the shape of the best fit line on the y versus x^2 graph tell you about the relationship between y and x^2?
3. If you plotted a graph of y versus x, how would the graph differ from the y versus x^2 graph?
4. What shape is the path of the projectile?

Experiment 5: Conservation of Energy

Required equipment

- Mini Launcher and ball
- Plumb bob and string
- Meter stick or measuring tape
- Tape
- White paper
- Carbon paper
- *Optional:* Photogate Mounting Bracket (ME-6821A) and any of the following photogate setups:
  - Wireless Smart Gate (PS-3225) and PASCO Capstone or SPARKvue
  - Smart Gate (PS-2180), any PASPORT interface, and PASCO Capstone or SPARKvue
  - 2× Photogate Heads (ME-9498A), a PASCO analog interface, and PASCO Capstone or SPARKvue
  - 2× Photogate Heads (ME-9498A) and a Smart Timer (ME-8930)

Purpose

The purpose of this experiment is to confirm that the initial kinetic energy of a projectile shot straight up is transformed into an equal amount of gravitational potential energy at the top of its arc.

Theory

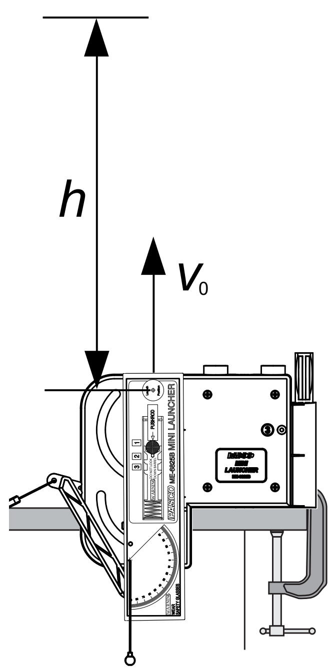
The total mechanical energy of a projectile is the sum of its gravitational potential energy and its kinetic energy. In the absence of friction, total mechanical energy is conserved. When a projectile is shot straight up, the initial gravitational potential energy (GPE) can be defined as zero. The initial kinetic energy (KE) depends on the mass m of the projectile and the initial speed v_0, as given by:

$$KE = \frac{1}{2}mv_0^2$$

When the projectile reaches its maximum height h, the speed of the projectile is zero, and therefore the kinetic energy is also zero. The gravitational potential energy depends on the mass of the projectile and the height, as given by:

$$GPE = mgh$$

where g is the acceleration due to gravity. If friction in the form of air resistance is ignored, the initial kinetic energy should equal the final gravitational potential energy.



In order to calculate the initial kinetic energy, the initial speed v_0 of the projectile must be determined. To calculate v_0 for a projectile fired horizontally, we can use a setup like what is shown below. The horizontal distance traveled by the projectile is given by $x = v_0 t$, where t is the time of flight for the projectile. In this case, the vertical distance that the projectile drops in time t is given by:

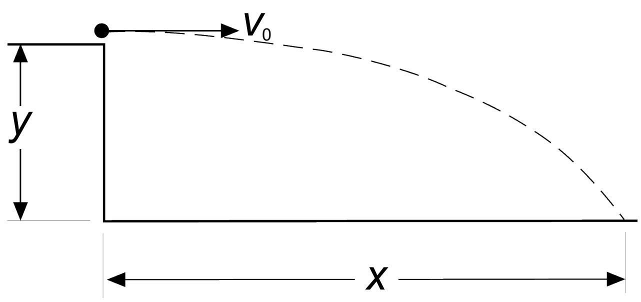
$$y = \frac{1}{2}gt^2$$

Solving this equation for t gives us:

$$t = \sqrt{\frac{2y}{g}}$$

From here, we can find the initial speed using the equation:

$$v_0 = \frac{x}{t}$$



Setup

1. Clamp the Mini Launcher stand near the corner of a sturdy table or other horizontal surface. Mount the Mini Launcher on the stand with the barrel aimed away from the table.
2. Point the Launcher straight up and fire a test shot on medium range to make sure the ball does not hit the ceiling. If it does, use the short range setting for this experiment or move the Launcher closer to the floor.
3. Adjust the angle of the Mini Launcher to zero degrees so the ball will be launched horizontally.

Procedure

Part 1A: Determine the initial speed without photogates

1. Put a ball into the Mini Launcher and cock it to the medium range setting. Fire one shot to locate where the ball hits the floor. At this position, tape a piece of white paper to the floor, then tape a piece of carbon paper, with the carbon side down, on top of the white paper. When the ball hits the carbon paper, it will leave a mark on the white paper.
2. Measure the vertical distance from the bottom of the ball as it leaves the barrel to the floor. Record this distance in the blank above Table 5.1.
3. Use a plumb bob to find the point on the floor that is directly beneath the launch position, as marked on the barrel. Measure the horizontal distance along the floor from this point to the leading edge of the piece of white paper. Record the distance in the blank above Table 5.1.
4. Fire ten shots.
5. Carefully remove the carbon paper, then measure the distance from the leading edge of the white paper to each of the ten dots. Record these distances in Table 5.1.
6. Find the average of the ten distances. Record this average distance in Table 5.1.
7. Calculate the total horizontal distance by adding the average distance and the distance from the launch position to the leading edge of the paper. Record this total distance in Table 5.1.
8. Use the vertical distance y to calculate the time of flight t, then use t and the total horizontal distance x to calculate the initial speed v_0. Record these values in the blanks below Table 5.1.

Part 1B: Alternate method for determining the initial speed (using photogates)

1. Attach a Photogate Mounting Bracket to the Mini Launcher. Secure a Smart Gate, Wireless Smart Gate, or two Photogate Heads to the bracket.
2. Connect the Smart Gate, Wireless Smart Gate, or Photogate Heads to PASCO Capstone or SPARKvue, using an appropriate interface if necessary. If you are using Photogate Heads, you can connect them to a Smart Timer instead.
3. Adjust the angle of the Launcher to 90° so that it points straight upward.
4. Load a ball into the Mini Launcher, using the pushrod to cock it at the medium range setting.

5. Set up the software or Smart Timer to measure the time between the ball blocking the two photogate beams. For more information on this, see the manual for the photogates or the PASCO Capstone or SPARKvue online help.
6. Begin recording data, then shoot the ball three times. Record the time values captured by the software or timer in Table 5.2.
7. Calculate the average of the three times. Record this average in Table 5.2.
8. Measure the distance between the photogates, then divide this value by the average time to obtain the initial speed v_0 of the ball. Record this value in the blank below Table 5.2.

Part 2: Measure the height of the ball

1. Adjust the angle of the Mini Launcher to 90° so that it points straight up.
2. Shoot the ball upward on the medium range setting several times. Measure the maximum height attained by the ball during these launches, then record this maximum height in Table 5.3.
3. Determine the mass of the ball, then record this mass in Table 5.3.

Data

Part 1A:

Vertical distance = _______________; Horizontal distance to edge of paper = _______________

Table 5.1: Data from Part 1A

Trial	Distance
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Total distance	

Calculated time of flight = _______________

Initial speed = _______________

Part 1B:

Table 5.2

Trial	Time
1	
2	
3	
Average time	

Initial speed = _______________

Analysis

1. Calculate the initial kinetic energy and record it in Table 5.3.
2. Calculate the final gravitational potential energy and record it in Table 5.3.
3. Calculate the percent difference between the initial kinetic energy and the final gravitational potential energy and record it in Table 5.3.

$$\left|\frac{KE - GPE}{\frac{KE+GPE}{2}}\right| \times 100\%$$

Table 5.3: Results

Item	Value
Maximum height of ball	
Mass of ball	
Initial kinetic energy (KE)	
Final potential energy (GPE)	
Percent difference	

Questions

1. How does the initial kinetic energy compare to the final gravitational potential energy?
2. Does friction in the form of air resistance affect the result for the conservation of energy?
3. When the Mini Launcher is cocked, it has elastic potential energy. If energy is conserved, how should the elastic potential energy compare to the initial kinetic energy?

Experiment 6: Conservation of Momentum

Required equipment

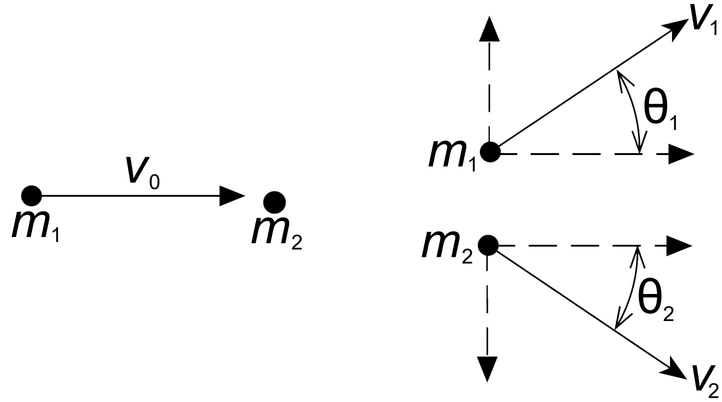
- Mini Launcher and 2× balls
- 2D Collision Accessory
- Plumb bob and string
- Meter stick or measuring tape
- Tape
- Large sheet of white paper
- 2-3 sheets of white paper
- Protractor

Purpose

The purpose of this experiment is to confirm that momentum is conserved for both elastic and inelastic collisions in two dimensions.

Theory

A ball is shot towards another ball that is initially at rest, resulting in a collision. After this, the two balls move apart in different directions. In the system consisting of just these balls, both balls are falling under the influence of gravity, so momentum is not conserved in the vertical direction. However, there is no net force in the horizontal plane (if air resistance is ignored), so momentum *is* conserved in the horizontal plane. The figure below illustrates the collision, with the left half showing the balls before the collision and the right half showing the balls after the collision.



Before collision, all the momentum is in the direction of Ball #1 (m_1); for convenience, we will define the x-axis in this direction. Before the collision, the total momentum is given by:

$$\vec{P}_{\text{before}} = m_1 v_0 \hat{x}$$

where v_0 is the initial speed of Ball #1 and $\hat{x}$ is the unit vector in the x-direction.

After the collision, the momenta of the two balls have both horizontal and vertical components. Therefore, the total momentum after the collision is given by the equation:

$$\vec{P}_{after} = (m_1 v_{1x} + m_2 v_{2x})\hat{x} + (m_1 v_{1y} + m_2 v_{2y})\hat{y}$$

where $v_{1x} = v_1\cos\theta_1$, $v_{1y} = v_1\sin\theta_1$, $v_{2x} = v_2\cos\theta_2$, $v_{2y} = v_2\sin\theta_2$.

Since there is no momentum in the y-direction before the collision, there is zero net momentum in the y-direction after the collision. Therefore:

$$m_1 v_{1y} = -m_2 v_{2y}$$

Equating the initial momentum in the x-direction with the x-direction momentum after the collision, we find that:

$$m_1 v_0 = m_1 v_{1x} + m_2 v_{2x}$$

In a perfectly elastic collision, kinetic energy is conserved as well as momentum. In this case, this would mean that:

$$\tfrac{1}{2} m_1 v_0^2 = \tfrac{1}{2} m_1 v_1^2 + \tfrac{1}{2} m_2 v_2^2$$

In addition, when kinetic energy is conserved and the colliding balls are of equal mass, the paths of the two balls after the collision will be at right angles to each other.

Setup

1. Clamp the Mini Launcher stand onto one edge of a sturdy table, oriented so the Launcher's barrel will face inward towards the table. Mount the Mini Launcher in the upper position on the stand.
2. Adjust the Mini Launcher's angle to 0° and slide the barrel forward over the alignment tab, ensuring that the ball will be fired horizontally.
3. Cover the table with white paper, such as butcher paper. This paper must reach the base of the Launcher.
4. Fire a test shot on the short range setting to make sure that the ball lands on the table. Tape a piece of carbon paper, with the carbon side down, over the spot where the ball lands.
5. Mount the 2D Collision Accessory to the front of the Launcher, as described in the main manual. Place a test ball onto the accessory's post.
6. Loosen the thumbscrew and rotate the 2D Collision Accessory slightly to one side. The post must be positioned so that the launched ball does not bounce back into the Mini Launcher but *does* hit the target ball, so that both balls land on the table at the same time. Once the post is in position, tighten the thumbscrew to secure the accessory in place.
7. Load the Mini Launcher and fire a test shot to make sure both balls hit the table at the same time. Tape a piece of carbon paper, with the carbon side down, at each spot where the two balls land on the table.

Procedure

Part 1: No collision

1. Load Ball 1 into the Mini Launcher and cock it to the short range setting. Do not place a target ball on the post.
2. Shoot the ball straight ahead and repeat the procedure five times.

Part 2: Elastic collision

1. Use two balls. Load Ball 1 into the Mini Launcher at the short range setting. Place Ball 2 on the post of the 2D Collision Accessory.
2. Shoot Ball 1 so that it collides with Ball 2. Repeat the procedure five times.

Part 3: Inelastic collision

1. Use two balls. Load Ball 1 into the Mini Launcher at the short range setting.
2. Put a small loop of sticky tape (sticky side out) on Ball 2 and place the ball onto the post. Orient the tape side of Ball 2 so that it will be struck by Ball 1, causing an inelastic collision.
3. Fire a test shot to locate where the two balls hit the table. Tape a piece of carbon paper to the white paper at this point.
4. Shoot Ball 1. If the two balls stick together but miss the carbon paper, relocate the paper and shoot once more.

> **NOTE:** Since the tape does not produce the same inelastic collision each time, it is only useful to record this collision once.

5. Use a plumb bob to locate the point on the paper directly below the point of contact between the two balls during the collision. Mark this spot on the paper as the "point of contact" spot. Carefully remove the carbon paper from the white paper.

Analysis

The vertical distance for each shot is the same, so the time of flight for each shot is also the same. Therefore, the horizontal length of each path is proportional to the speed of the ball. Since the masses are the same, the horizontal length of each path is also proportional to the momentum of the ball.

Part 1: No collision

1. Draw straight lines from the "point of contact" spot to each of the dots made by the shots in Part 1.
2. Measure each straight line and record the length. Find the average of the five lengths and record this value as the "**Initial x-momentum**" in Tables 6.1 and 6.2. (For example, if the length is 65 cm, record "65" as the value but do not include any units.)

Part 2: Elastic collision

1. Draw a straight line from the "point of contact" through the *center* of the dots made by the "no collision" shots. This is the center line from which all of the angles will be measured.
2. Draw straight lines from the "point of contact" spot to each of the dots made by the shots in Part 2.
3. Measure the distance from the "point of contact" spot to the each of the dots made by Ball 1, then find the average of these five lengths.
4. Draw a straight line from the "point of contact" spot through the center of the group of dots made by Ball 1. Measure the angle between the center line and this straight line, then use this angle and the average length from Step 3 to calculate the x-component and y-component of horizontal distance for Ball 1. Record the x-momentum on a separate paper, and record the y-momentum in Table 6.1 as "**Final y-momentum, Ball 1**".

5. Measure the distance from the "point of contact" spot to the each of the dots made by Ball 2, then find the average of these five lengths.
6. Draw a straight line from the "point of contact" spot through the center of the group of dots made by Ball 2, then measure the angle between the center line and this straight line. Use this angle and the average length from Step 5 to calculate the x-component and y-component of horizontal distance for Ball 2. Record the x-momentum on a separate paper, and record the y-momentum in Table 6.1 as "**Final y-momentum, Ball 2**".
7. Add the x-momentum for Ball 1 that you obtained in Step 4 and the x-momentum of Ball 2 that you obtained in Step 6. Record these values in Table 6.1 as "**Final x-momentum, Ball 1 + Ball 2**" in Table 6.1.
8. Calculate the initial kinetic energy of Ball 1 before the collision. Record this value as "**Initial kinetic energy, Ball 1**" in Table 6.1.
9. Calculate the *total* final kinetic energy of both balls after the collision. Record this value as "**Final kinetic energy, Ball 1 + Ball 2**" in Table 6.1.
10. Calculate the percent differences between the two values on each row of Table 6.1. Record these percent differences in the final column.

Table 6.1: Data for the elastic collisions.

Item	Value	Item	Value	Percent difference
Initial x-momentum, Ball 1		Final x-momentum, Ball 1 + Ball 2		
Final y-momentum, Ball 1		Final y-momentum, Ball 2		
Initial kinetic energy, Ball 1		Final kinetic energy, Ball 1 + Ball 2		

Part 3: Inelastic collision

1. Draw straight lines from the "point-of-contact" spot to the pair of dots made by the inelastic collision shot from Part 3.
2. Measure both of the lines from the previous step.
3. Measure the angle from the center line to the straight line for each dot of the inelastic collision shot.
4. Using the angles and lengths from Steps 2 and 3, determine the x-component and y-component for each ball in the shot. Record the x-components on a separate paper, and record the y-components in Table 6.2 as "**Final y-momentum, Ball 1**" and "**Final y-momentum, Ball 2**".
5. Add the x-momentum for Ball 1 and the x-momentum for Ball 2 to obtain the total x-momentum after the collision. Record this value in Table 6.2 as "**Final x-momentum, Ball 1 + Ball 2**".
6. Calculate the initial kinetic energy of Ball 1, then calculate the sum of the kinetic energy of Ball 1 and Ball 2 after the collision. Record these values in Table 6.2 as "**Initial kinetic energy, Ball 1**" and "**Final kinetic energy, Ball 1 + Ball 2**".
7. Calculate the percent differences between the two values on each row of Table 6.2. Record these percent differences in the final column.

Table 6.2: Data for the inelastic collision.

Item	Value	Item	Value	Percent difference
Initial x-momentum, Ball 1		Final x-momentum, Ball 1 + Ball 2		
Final y-momentum, Ball 1		Final y-momentum, Ball 2		
Initial kinetic energy, Ball 1		Final kinetic energy, Ball 1 + Ball 2		

Questions

1. Was momentum conserved in the *x*-direction for each type of collision?
2. Was momentum conserved in the *y*-direction for each type of collision?
3. Was kinetic energy conserved for the elastic collision?
4. Was kinetic energy conserved for the inelastic collision?

Experiment 7: Vary the Angle to Maximize the Height

Required equipment

- Mini Launcher and ball
- Plumb bob and string
- Board (to protect wall)
- Meter stick or measuring tape
- Tape
- Large sheet of white paper
- Several sheets of carbon paper

Purpose

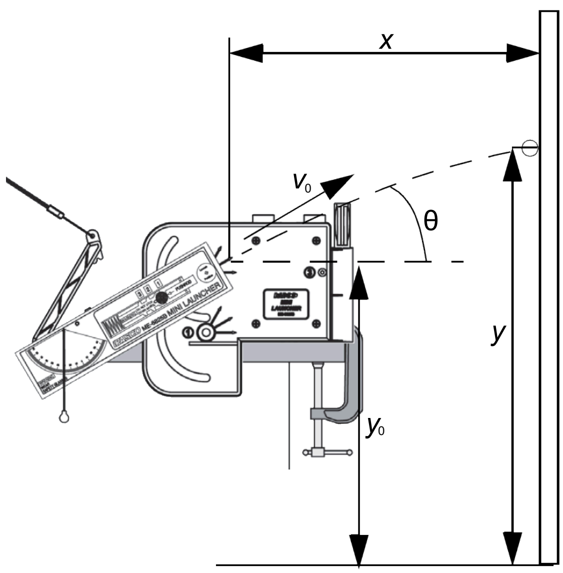
The purpose of this experiment is to find the launch angle that will maximize the height on a vertical wall for a projectile launched at a fixed horizontal distance from the wall.

Theory

When a ball is shot at an angle θ at a fixed distance *x* away from a target, such as a vertical wall, the ball will hit the target at a height *y* given by:

$$y = y_0 + (v_0 \sin\theta)t - \tfrac{1}{2}gt^2$$

where y_0 is the initial height of the ball, v_0 is the initial speed of the ball as it leaves the muzzle, *g* is the acceleration due to gravity, and *t* is the time of flight. (See below.)



The horizontal distance *x* that the ball travels in time *t* is given by:

$$x = (v_0 \cos\theta)t$$

We can solve this equation to obtain the time of flight *t*:

$$t = \frac{x}{v_0 \cos\theta}$$

Plugging this into the equation for *y*, we get:

$$y = y_0 + x\tan\theta - \frac{gx^2}{2v_0^2\cos^2\theta}$$

To find the angle that gives the maximum height *y*, start by taking the first derivative of the equation for *y* with respect to *t* and set this derivative equal to 0. The derivative is given by:

$$\frac{dy}{d\theta} = x\sec^2\theta - \frac{gx^2\tan\theta\sec^2\theta}{v_0^2}$$

Setting this derivative equal to 0 at the maximum angle θ_{max}, we can solve for θ_{max} to find that:

$$\tan\theta_{max} = \frac{v_0^2}{gx}$$

Since the second derivative at this angle is negative, the angle θ_{max} is a maximum.

To find the initial speed of the ball, use the fixed distance x and the maximum height y_{max}. Solve the y-equation for v_0 and plug in the values of y_{max}, θ_{max}, and x.

Setup

1. Clamp the Mini Launcher stand near one corner of a sturdy table, oriented so that the barrel will point off the table. Mount the barrel in the upper position with the muzzle aligned with the upper pivot hole.
2. Aim the barrel toward a wall about two meters from the table.
3. Place a vertical board in front of the wall to protect it from damage. Cover this board with white paper.
4. Fire a test shot to see where the ball hits the board. Tape a piece of carbon paper, with the carbon side down, at this position.

Procedure

1. Shoot the ball at various angles. Identify which angle gives the maximum height by checking the marks on the white paper. (Move the carbon paper as necessary.)
2. Measure the angle that produces the maximum height and record its value in Table 7.1.
3. Measure the maximum height and record the value in Table 7.1.
4. Measure the horizontal distance from the muzzle to the vertical board and record the value in Table 7.1.
5. Measure the initial height of the ball where it leaves the muzzle and record the value in Table 7.1.

Analysis

1. Calculate the initial speed by solving the y-equation for v_0 and substituting the values for y_{max}, θ_{max}, and x from Table 7.1.
2. Calculate the angle for maximum height using the initial speed calculated in the previous step and the horizontal distance from the wall to the Launcher.
3. Calculate the percent difference between the measured angle and the calculated angle. To do so, let A be one of the angles and B be the other angle, then use the equation:

$$\text{Difference} = \left|\frac{A - B}{\frac{A+B}{2}}\right| \times 100\%$$

Table 7.1: Data and results

Item	Value
Measured angle for maximum height (θ_{max})	
Maximum height (y_{max})	
Horizontal distance (x)	
Initial height (y_0)	
Calculated initial speed (v_0)	
Calculated angle for maximum height (θ_{max})	
Percent difference between angles	

Questions

1. For the angle that gives the maximum height, when the ball hits the wall, has it already reached the peak of its trajectory?
2. For what distance from the wall would the height be maximized for a launch angle of 45°? What would the maximum height be in this case?

Experiment 8: Do 30° and 60° Give the Same Range? (Demonstration)

Required equipment

- Mini Launcher and ball

Purpose

The purpose of this demonstration is to confirm that the range of a ball launched at 30° is the same as one launched at 60° if the ball lands at the same height from which it was launched.

Theory

The range is the horizontal distance x between the muzzle of the Mini Launcher and the point where the projectile lands. This range is given by the equation $x = (v_0\cos\theta)t$, where v_0 is the ball's initial speed as it leaves the muzzle, θ is the launch angle above the horizontal, and t is the time of flight.

If the ball lands on a target that is at the same height as the level of the muzzle of the Mini Launcher, the time of flight of the ball will be twice the time it takes the ball to reach the peak of its trajectory, when its vertical component of speed reaches zero. We express this as:

$$t = 2t_{\text{peak}} = \frac{2v_0\sin\theta}{g}$$

where g is the acceleration due to gravity. Substituting this for t in the range equation, we find that:

$$x = \frac{2v_0^2\sin\theta\cos\theta}{g}$$

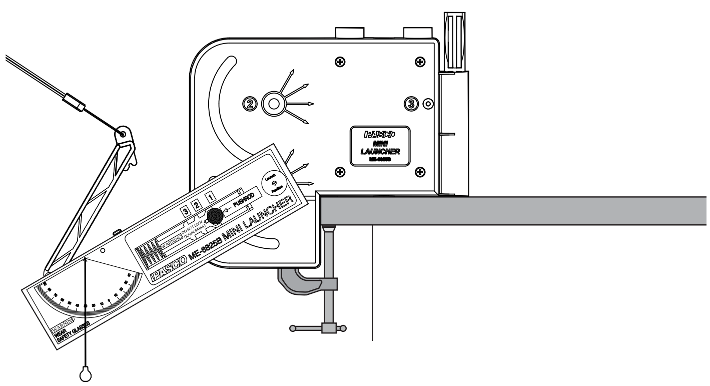
We can simplify this equation with a trigonometric identity to obtain:

$$x = \frac{v_0^2\sin(2\theta)}{g}$$

Plugging in either 30° or 60° to this equation will yield the same result, since sin(60°) = sin(120°). Therefore, firing a projectile at a 30° angle above the horizontal should yield the same range as firing the same projectile at a 60° angle.

Setup

1. Clamp the Mini Launcher stand to the edge of a sturdy table. Mount the launcher in the lower position with the barrel aimed toward the middle of the table, as shown below.



2. Adjust the angle of the Mini Launcher to 30°. Adjust the position of the barrel so that the muzzle is at the same level as the table top.
3. Load a ball into the Mini Launcher and cock it to the medium range or long range setting. (This demonstration will generally not work as well on the short range setting, as the muzzle speed on this setting is more variable with the change in angle.)
4. Fire a test shot to see where the ball hits.

Procedure

1. Shoot the ball at 30° and mark where the ball lands on the table.
2. Change the angle of the Mini Launcher to 60° and shoot the ball again. Emphasize the fact that the ball lands on the same mark where the first ball landed, confirming that the ranges are the same.
3. Change the angle to 45° and shoot the ball again to show that the ball now lands further away, landing beyond the mark for the previous angles.
4. Ask the students: What other pairs of angles will have a common range? Will 20° and 70° have the same range? Will 35° and 55° have the same range? (This demonstration can be done for any two angles that add up to 90°.)

Experiment 9: Simultaneous Shots at Different Speeds (Demonstration)

Required equipment

- 2× Mini Launchers and balls
- 2× rod stands and vertical rods

Purpose

The purpose of this demonstration is to confirm that projectiles fired horizontally will hit the floor at the same time, regardless of their initial speeds.

Theory

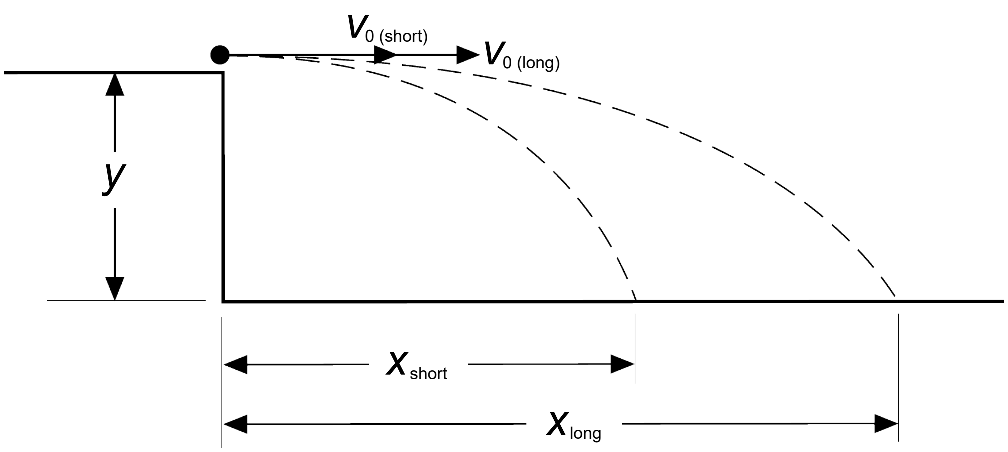
In this demonstration, two projectiles are shot horizontally from the same height y. The muzzle speeds of the two projectiles are different.

The vertical and horizontal motions of a projectile are independent of each other. The horizontal distance x traveled by the projectile depends on the initial speed v_0 and the time of flight t. This relationship is given by $x = v_0 t$.

The time of flight depends on the vertical distance y that the projectile falls, as given by:

$$t = \sqrt{\frac{2y}{g}}$$

where g is the acceleration due to gravity. Since the vertical distance is the same for both projectiles, the time of flight should also be the same for each projectile.



Setup

1. Mount two Mini Launcher stands at the same height on adjacent vertical rods which have been secured in place on a sturdy table. Mount the Mini Launchers on the stands so that their barrels point off the table.
2. Adjust the angle of both Mini Launchers to 0°, then slide the barrels forward over the alignment tabs so that both balls will be fired horizontally.

Procedure

1. Load a ball into each Mini Launcher. Cock one Mini Launcher to the short range setting, then cock the other to the long range setting.
2. Ask the class to be quiet and listen for the balls striking the floor. If there is only one click, that means that the balls hit the floor simultaneously.
3. Place both trigger release lanyards in the same hand and pull them at the same time, so that the balls are launched simultaneously.
4. After the balls hit the floor, ask the students if they heard one click or two.

Experiment 10: Shooting Through Hoops (Demonstration)

Required equipment

- Mini Launcher and ball
- 5× ring clamps on stands
- Meter stick
- Two-meter stick
- *Optional:* Photogate Mounting Bracket (ME-6821A) and any of the following photogate setups:
  - Wireless Smart Gate (PS-3225) and PASCO Capstone or SPARKvue
  - Smart Gate (PS-2180), any PASPORT interface, and PASCO Capstone or SPARKvue
  - 2× Photogate Heads (ME-9498A), a PASCO analog interface, and PASCO Capstone or SPARKvue
  - 2× Photogate Heads (ME-9498A) and a Smart Timer (ME-8930)

Purpose

The purpose of this demonstration is to confirm that the path of a projectile is parabolic.

Theory

The horizontal distance x between the muzzle of a Mini Launcher and the point where the projectile hits is given by $x = v_0 t$, where v_0 is the initial speed of the projectile as it leaves the muzzle and t is the time of flight. If the projectile is fired horizontally, its vertical position y at time t is given by:

$$y = y_0 - \tfrac{1}{2}gt^2$$

where y_0 is the initial height of the projectile and g is the acceleration due to gravity. Solving the x-equation for t and substituting this equation into the y-equation, we get:

$$y = y_0 - \tfrac{1}{2}g\left(\frac{x}{v_0}\right)^2 = \left(-\frac{g}{2v_0^2}\right)x^2 + y_0 = ax^2 + b$$

where a and b are constants. The equation $y = ax^2 + b$ describes a parabola.

Pre-lab

Before the demonstration begins, find the initial speed of the ball using one of the following methods:

- Attach a Photogate Mounting Bracket to the Mini Launcher. Mount a Wireless Smart Gate (PS-3225), a Smart Gate (PS-2180) connected to a PASPORT interface, or two Photogate Heads (ME-9498A) connected to an analog interface or a Smart Timer (ME-8930). Connect the gates to PASCO Capstone or SPARKvue data collection software (or to the Smart Timer) and measure the initial speed of the ball.
- Shoot the ball horizontally and measure the horizontal distance x and vertical distance y traveled. Use y to calculate the time of flight t, then use x and t to calculate the muzzle velocity.

For more information on these methods, see Experiments 1 and 2.

Setup

1. Clamp the Mini Launcher stand near the corner of a sturdy table. Mount the Launcher so that it is aimed away from the table.
2. Adjust the angle of the Launcher to 0° and slide the barrel over the alignment tab so the ball will be fired horizontally.

Procedure

1. Measure and record the initial height y_0 of the ball at muzzle level.
2. Calculate and record the horizontal and vertical positions of the ball each 1/10 second until the vertical position is zero, using the equations in the **Theory** section.
3. Lay the two-meter stick on the floor in a straight line away from the Mini Launcher.
4. Starting at the muzzle of the Mini Launcher, measure off each set of x and y distances and place a ring clamp on a stand at each position corresponding to one-tenth of a second. (See Figure 10.1.)
5. Shoot the ball through the rings.
6. Ask the students: What shape of curve is formed by the rings? What is the path of the projectile?

Table 10.1: x- and y-positions

t (s)	$x = v_0 t$ (cm)	$y = y_0$ - ½gt^2 (cm)
0.1		
0.2		
0.3		
0.4		
0.5		

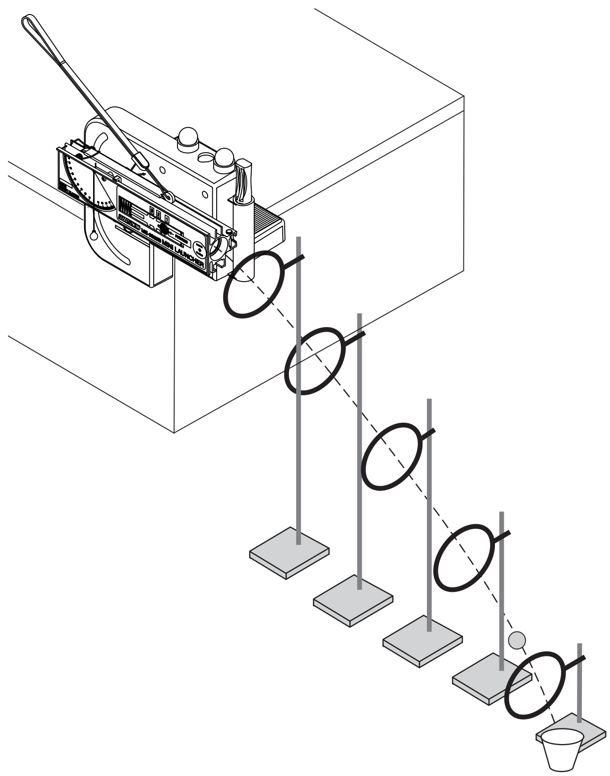


Figure 10.1: Demonstration setup.

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