PASCO®

Mini Launcher
ME-6825B

Contents

Mini Launcher

ME-6825B

Included Items	Included Items
(1) Safety Glasses	(5) 2-D Collision Accessory
(2) Mini Launcher Stand	(6) Mini Launcher
(3) Steel balls, 16 mm (2)	(7) Metal Weight
(4) Pushrod	(8) Lanyard

Recommended Items*

Large C-clamp (SE-7285, pack of six)	Large Table Clamp (ME-9472)
45 cm Stainless Steel Rod (ME-8736	Launcher Spare Weights (ME-9868, 24-pack)

Other Items*

Smart Gate (PS-2180) or Photogate Head (ME-9498A)

Photogate Mounting Bracket (ME-6821A)

Time-of-Flight Accessory (ME-6810A)

Mini Launcher Ballistic Pendulum Accessory (ME-6829)

(*See the PASCO catalog or the PASCO web site at www.pasco.com for more information.)

Introduction

The PASCO Mini Launcher has been designed for projectile experiments and demonstrations. The only additional equipment required is a C-clamp for clamping the stand to a table or a Large Table Clamp (ME-9472) for clamping the stand to a support rod. The features of the Mini Launcher include:

•   LAUNCH AT ANY ANGLE Between -45° and 90°:

The ball can be launched at any angle from 0 to 90 degrees measured above the horizontal. The magnetic piston holds the steel ball in position for launch at any angle from 0 to 45 degrees measured below the horizontal.

The angle is easily adjusted using the thumb screws. The built-in protractor and metal weight on the side of the launcher give a convenient and accurate way of determining the angle of inclination.
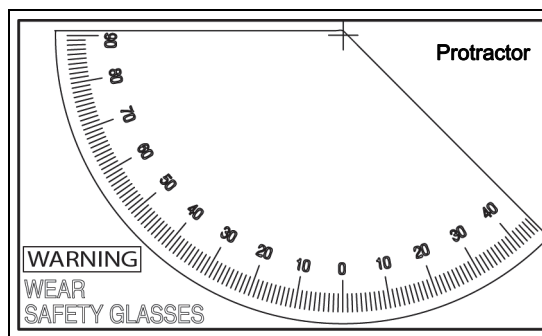
•   THREE RANGE SETTINGS:
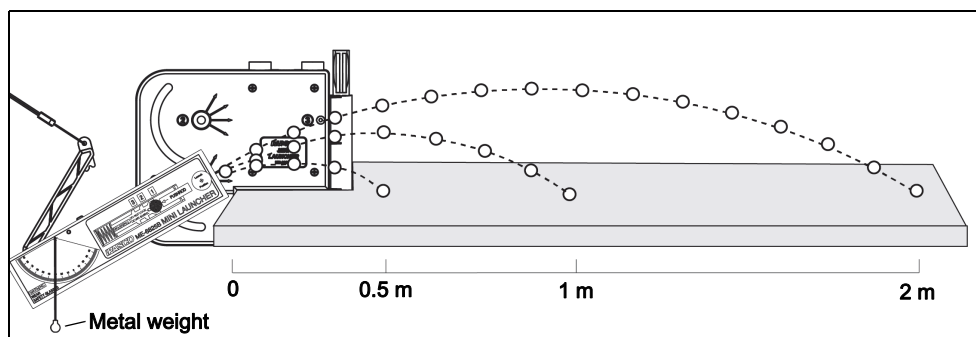
There are three ranges from which to choose. They are approximately 0.5 meter, 1.0 meter, and 2.0 meters, when the angle is 45 degrees and measured from table top to table top.

PASCO ®

• FIXED ELEVATION INDEPENDENT OF ANGLE:

The Mini Launcher can be mounted so that the barrel pivots at the muzzle end and the elevation of the ball as it leaves the barrel does not change as the angle is varied.

• REPEATABLE RESULTS:

There is no spin on the ball since the piston keeps the ball from rubbing on the walls as it travels up the barrel. The sturdy base can be secured to a table with a C-clamp or a Large Table Clamp (not included) so there is very little recoil. The trigger is pulled with a lanyard to minimize jerking.

• COMPUTER COMPATIBLE:

A Smart Gate or Photogates may be attached with a Photogate Mounting Bracket (ME-6821A) to connect the Mini Launcher to a computing device to measure the muzzle speed. You can also use a Time-of-Flight Accessory and a Smart Gate or Photogate to measure the time of flight.
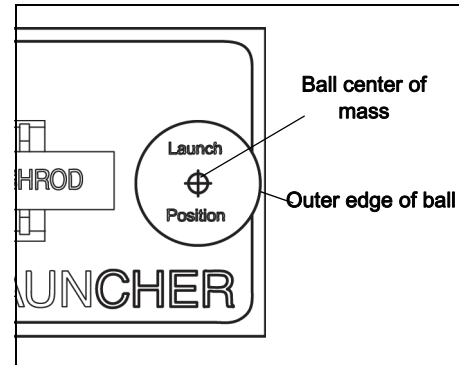
General Operation

Ready

Always wear safety goggles when you are in a room where the Mini Launcher is being used.

CAUTION: Never look down the front of the barrel because it may be loaded. Safety goggles are provided for use when operating the Mini Launcher. Always assume that the barrel is loaded!

The base of the Mini Launcher can be fastened to the edge of a table using a clamp of your choice. See the Launch Position Examples section for 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 be mounted to shoot onto a table such that the launch position of the ball is at the same height as the landing position on the table.

NOTE: To prevent the steel ball from denting the floor or table top, you may want to place a protective covering on the surface.

Aim

The angle of inclination is adjusted by loosening the thumb screws on the back of the stand and rotating the barrel of the Mini Launcher to the desired angle above or below the horizontal as indicated by the hanging weight and protractor on the side of the Mini Launcher. (See the Launch Position Examples section.) When the Mini Launcher is at the desired angle, tighten the thumb screws.

Load

Always cock the Launcher with a ball in the piston. **NOTE**: Use only 16 millimeter steel balls with the Mini Launcher.

Place a ball in the barrel. Push the ball down the barrel with the pushrod until the trigger catches a notch on the piston. One audible click indicates that the trigger is holding the piston 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.

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.
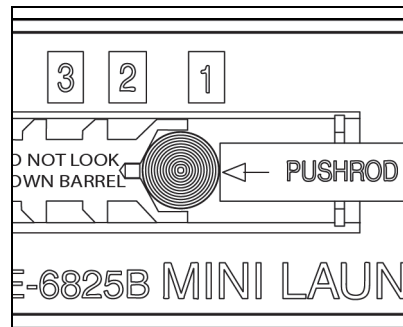
Shoot

Before launching the ball, make certain that no person is in the way.

To shoot the ball, pull upward on the lanyard to release the trigger. It is only necessary to pull upward about a centimeter.

Storage

Store the Mini Launcher with the spring uncompressed. (Do not leave it in a cocked position.)

Installing the Optional Photogate Bracket

The Photogate Mounting Bracket is an optional accessory for mounting a Smart Gate or one or two Photogates on the front of the Mini Launcher. Using a Smart Gate or Photogates and a computing device with a PASCO Interface and Data Collection Software is one way to determine the muzzle velocity of the ball.

Installation is as follows:

• Prepare the Photogate Mounting Bracket by loosening the thumb screw near the end of the bracket that holds the square nut. Attach the Smart Gate or Photogate(s) to the bracket by placing the Smart Gate or Photogate between the alignment ridges on the bracket and fastening them in place with the small thumb screw(s).

• Align the square nut with the T-slot on the bottom of the Mini Launcher barrel and slide the nut into the slot. Slide the bracket into the slot until the Smart Gate or Photogate closest to the barrel is as close as possible without blocking the infrared beam. Tighten the thumbscrew to secure the bracket.

• When storing the Mini Launcher, the photogate mounting bracket does not need to be removed. Slide it back along the barrel with or without photogates in place, making the package as compact as possible.
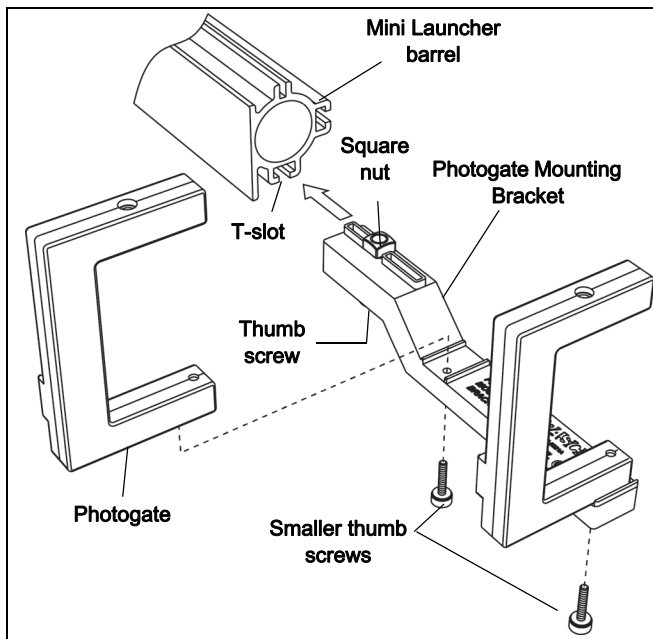
Installing the 2-Dimensional (2-D) Collision Accessory

The 2-D Collision Accessory consists of a thumbscrew, a square nut, and a molded plastic piece. The plastic piece has text on both sides. One side is "PASCO 2-D COLLISION ACCESSORY" and the other side is "USE THIS SIDE FOR MINI LAUNCHER". (The item can be used with any PASCO Projectile Launcher.)

Assemble the 2-D Collision Accessory with the "USE THIS SIDE FOR MINI LAUNCHER" facing up. Put the thumbscrew through the hole from the bottom and add the square nut from the top. Leave the thumbscrew slightly loose.

Align the square nut with the T-slot on the bottom of the Mini Launcher barrel and slide the square nut into it. To use the 2-D Collision Accessory, place a ball on the top of the post. Rotate the 2-D Collision Accessory to one side or the other until the ball on the post is in a position where it will be hit by a launched ball at the angle that you want (without causing the launched ball to bounce back against the barrel).
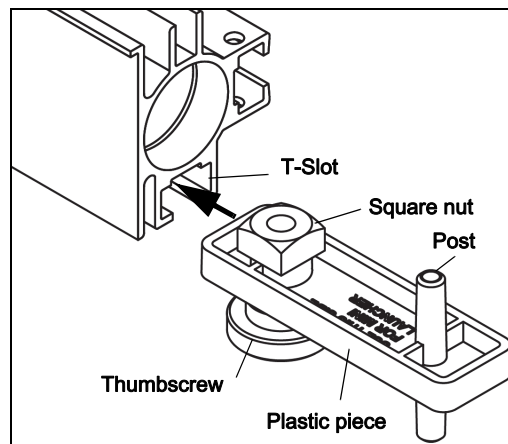
Expectations for the Mini Launcher

The following are helpful hints and approximate values you may find useful:

•   The muzzle speed will vary slightly with angle. The difference between muzzle speed when shot horizontally versus vertically can be anywhere from zero to eight percent, depending on the range setting and the particular launcher.

•   The scatter pattern is minimized when the Mini Launcher stand is securely clamped to a sturdy table. Any wobble in the table will show up in the data.

•   The angle of inclination can be determined to within one- half of a degree with the protractor.

Launch Position Examples

The Mini Launcher barrel 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.

The stand has a lower pivot hole marked as ① and an upper pivot hole marked as ② and an upper curved slot and a lower curved slot. The upper curved slot allows the Mini Launcher to shoot the ball at a positive or a negative angle. The lower curved slot allows launch angles from 0 to 90°.At the same height as the upper pivot hole and at the front edge of the stand is an alignment tab marked as ③.

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 (③).
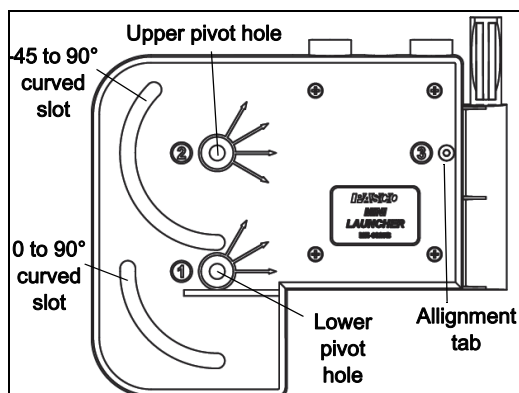
- Example 1: Clamp the Mini Launcher stand to a table and mount the barrel in the lower position with the muzzle aligned with the pivot hole (①). The Mini Launcher will be able to shoot onto the table from the same level as the table. To do this, slide the square nut that the barrel pivots around to the front of the T-slot on the side of the launcher. The ball is launched with a positive angle at table level. When you change the angle of the launcher, the elevation of the launch position does not change.

- Example 2: Clamp the Mini Launcher base to a table and mount the barrel in the upper position on the stand using the upper pivot hole (②). Slide the barrel forward so that the T-slot on the side of the launcher fits over the alignment tab (③). Put the muzzle even with or slightly beyond the front edge of the stand when using the Mini Launcher Ballistic Pendulum Accessory (ME-6829). In this position the launch angle is 0° to shoot the ball horizontally from a constant height.

- Example 3A: Clamp the Mini Launcher base to the side edge of a table. Mount the launcher in the lower position to shoot from the table onto the floor at a positive angle from the same elevation.

- Example 3B: Mount the launcher in the upper position to shoot from the table onto the floor at a negative angle from the same elevation.

- Example 4: Mount the Mini Launcher stand on a vertical support rod. Put the barrel in any of the positions described above.

Example 1

Example 2

Example 3A

Example 3B

Example 4
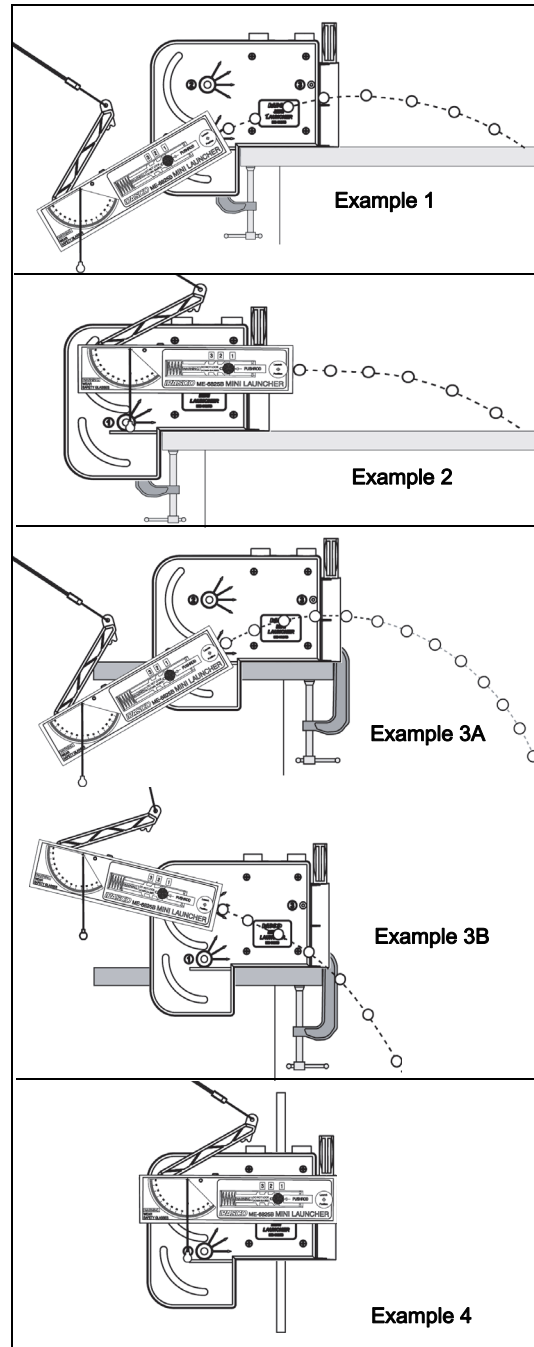
Exp. 1: Projectile Motion

Equipment Needed

Item	Item
Mini Launcher and ball	Plumb bob and string
Meter stick	Carbon paper
White paper	Sticky 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 muzzle of the Mini Launcher.

Theory

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

Initial Horizontal Speed

For a ball shot horizontally from a table with an initial speed, v_0, the horizontal distance travelled by the ball is given by $x = v_0 t$, where t is the time the ball is in the air. (Neglect air friction.)

The vertical distance of the ball is the distance it drops in time t given by

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

The initial speed can by determined by measuring x and y. The time of flight, t, of the ball can be found using

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

and the initial horizontal speed can be found using $v_0 = \frac{x}{t}$.

Initial Speed at an Angle

To predict the horizontal range, x, of a ball shot with an initial speed, v_0, at an angle, θ, above the horizontal, first predict the time of flight from the equation for the vertical motion:

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

where y_0 is the initial height of the ball and y is the position of the ball when it hits the floor. In other words, solve the quadratic equation for t and then use $x = v_0 \cos\theta\, t$ where $v_0 \cos\theta$ is the horizontal component of the initial speed.

Setup

1. Clamp the Mini Launcher stand to a sturdy table or other horizontal surface with the launcher aimed away from the table.

1. Mount the Mini Launcher in the upper position with the T-slot at the muzzle end on the alignment tab.

• In this position the Mini Launcher will launch the ball horizontally.
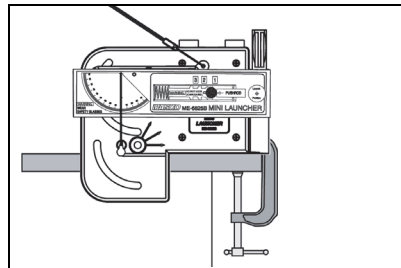
Part A: Determining the Initial Horizontal Speed of the Ball

1. Put a ball in the Mini Launcher and use the push-rod to cock it at the long range position. Fire one shot to locate where the ball hits the floor. At that point, tape a piece of white paper to the floor. Place a piece of carbon paper (carbon-side down) on top of the white paper and tape it in place.

• When the ball hits the carbon paper on the floor, it will leave a mark on the white paper.

2. Fire ten shots.

3. Measure the vertical distance from the bottom of the ball as it leaves the barrel to the floor. Record this distance in the Data Table.

4. Use a plumb bob to find the point on the floor that is directly beneath the release point on the barrel. Measure the horizontal distance along the floor from the release point to the leading edge of the piece of white paper. Record the distance in the Data Table.

5. 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 the Data Table and find the average. Calculate and record the total horizontal distance (distance to paper plus average distance from edge of paper to dots).

6. 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 the time and speed in the Data Table.
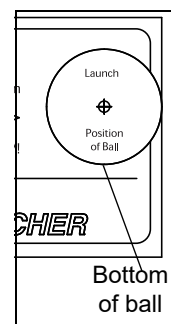
Part B: Predicting the Range of a Ball Shot at an Angle

1. Adjust the angle of the Mini Launcher to an angle between 30 and 60 degrees. Record this angle in the second Data Table.

2. Using the initial speed and vertical distance from the first part of this experiment, calculate the new time of flight and the new horizontal distance based on the assumption that the ball is shot at the new angle you have just selected. Record the predictions in the second Data Table.

3. Draw a line across the middle of a white piece of paper and 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.

4. Shoot the ball ten times.

5. Carefully remove the carbon paper. Measure the distances to the ten dots and record the distances in the second Data Table.
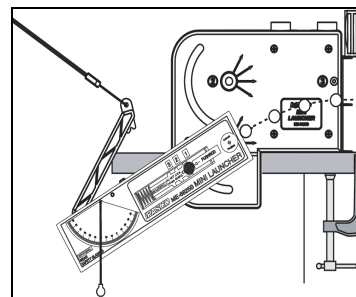
Data Table A: Determine the Initial Speed

Vertical distance = _____ Horizontal distance to edge of paper = _____

Calculated time of flight = _____ Initial speed = _____

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

Data Table B: Predict the Range

Angle above horizontal = _____ Horizontal distance to edge of paper = _____

Calculated time of flight = _____ Predicted range = _____

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.

$$\frac{|theoretical - actual|}{theoretical} x100$$

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

Notes

Exp. 2: Projectile Motion Using Photogates

Equipment Needed

Item	Item
Mini Launcher and ball	Plumb bob and string
Photogate Head ME-9498A (2) **OR** PASCO Smart Gate PS-2180	
Photogate Mounting Bracket ME-6821A	
PASCO Interface* and PASCO Data Collection Software* **OR** Smart Timer* ME-8930	
Meter stick	Carbon paper
White paper	Sticky tape

See the PASCO web site at www.pasco.com for information about PASCO interfaces, timers, and software.

Purpose

The purpose of this experiment is to predict and verify the range of a ball launched at an angle. Photogates are used to determine the initial speed of the ball.

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, it is first necessary to determine the initial speed (muzzle velocity) of the ball. The speed can be determined by shooting the ball and measuring a time using photogates. To predict the range, x, of the ball when it is shot with an initial speed at an angle, θ, above the horizontal, first predict the time of flight using the equation for the vertical motion:

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

where y_0 is the initial height of the ball and y is the position of the ball when it hits the floor. Solve the quadratic equation to find the time, t. Use $x = (v_0 \cos\theta)\,t$ to predict the range.

Setup

1. Clamp the Mini Launcher to a sturdy table or other horizontal surface. Mount the Mini Launcher near one end of the table.

2. Adjust the angle of the Mini Launcher to an angle between 30 and 60 degrees and record the angle.

3. Attach the photogate mounting bracket to the Mini Launcher and attach one Smart Gate or two Photogate Heads to the bracket. If you are using photogates, check that the distance between the photogates is 0.10 m (10 cm).

4. Plug the Smart Gate or the two Photogate Heads into an interface. If you are using a timer, plug the two Photogate Heads into the timer.
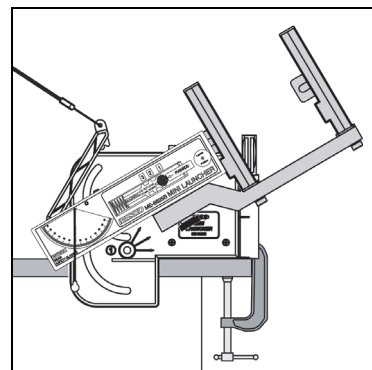
Procedure

Part A: Determining the Initial Speed of the Ball

1. Put a ball in the Mini Launcher and use the push-rod to cock it at the long range position.

2. Setup the software to measure the time between the ball blocking the Smart Gate or the two Photogate Heads. [OR set up a timer to measure the time between the ball blocking the two Photogate Heads.

3. Shoot the ball three times and calculate the average of these times. Record the data in the Data Table.

4. Calculate the initial speed of the ball based on the distance and the time. Record the value.

Data Table: Part A

Table 1: Determine the Initial Speed

Trial	Time
1	
2	
3	
Average Time	
Initial Speed	

Part B: Predicting the Range of a Ball Shot at an Angle

1. Keep the angle of the Mini Launcher at the original angle above horizontal.

2. Measure the vertical distance from the bottom of the ball as it leaves the barrel to the floor. Record this distance in the second Data Table.

3. Use the vertical distance, the angle, and the initial speed to calculate the time of flight. Record the value.

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

Launch

⊕

Position
of Ball

Bottom
of ball
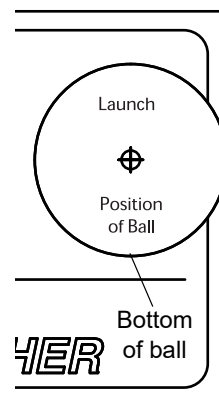
4. Use the time of flight, t, angle, θ, and initial speed, v_0, to predict the horizontal distance
(range, $x = (v_0 \cos\theta)\,t$). Record the predicted range.

5. Draw a line across the middle of a white piece of paper and tape the paper on the floor so the line is at the predicted horizontal distance. Cover the white paper with carbon paper and tape the carbon paper in place.

6. Use a plumb bob to find the point on the floor that is directly beneath the release point on the barrel. Measure the horizontal distance along the floor from the release point to the leading edge of the piece of white paper. Record the distance in the Data Table.

7. Shoot the ball ten times.

8. 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 the Data Table and find the average. Calculate and

record the total horizontal distance (distance to paper plus average distance from edge of paper to dots).

Angle above horizontal = _____ Horizontal distance to edge of paper = _____

Calculated time of flight = _____ Predicted range = _____

Data Table: Part B

Table 2: Confirm the Predicted Range

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.

$$\frac{|theoretical - actual|}{theoretical} x100$$

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

Notes

Exp. 3: Projectile Range versus Angle

Equipment Needed

Item	Item
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: for shooting on level ground and for shooting off a table.

Theory

The range is the horizontal distance, x, between the muzzle of the Launcher and the place where the projectile hits, given by $x = (v_0 \cos \theta)\, t$, where v_0 is the initial speed of the projectile as it leaves the muzzle, θ is the launch angle above horizontal, and t is the time of flight. See the figure.
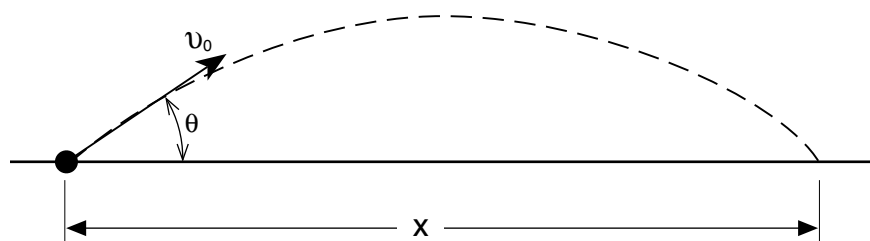
Figure 3.1: Shooting on a level surface

For the case in which the projectile hits on a surface that is the same level as the level of the muzzle of the Launcher, the time of flight of the projectile will be twice the time it takes for the projectile to reach the peak of its trajectory. At the peak, the vertical speed is zero, so:

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

where v_0 is the initial speed of the projectile. Solving for the time gives an expression for the total time of flight as:

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

For the case in which the projectile is launched at an angle above horizontal from a table onto the floor, the time of flight is found using the equation for vertical motion

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

where y_0 is the initial height of the projectile in the Launcher and y is the vertical position of the ball when it hits the floor.

Figure 3.2: Shooting from a table

Setup

1. Clamp the Mini Launcher stand to a sturdy table or other horizontal surface near one end of the table, but aim it toward the center of the table rather than away from the table.

2. Mount the barrel in the lower position on the stand. Align the muzzle with the lower pivot hole. Adjust the angle of the Mini Launcher to 10 degrees.
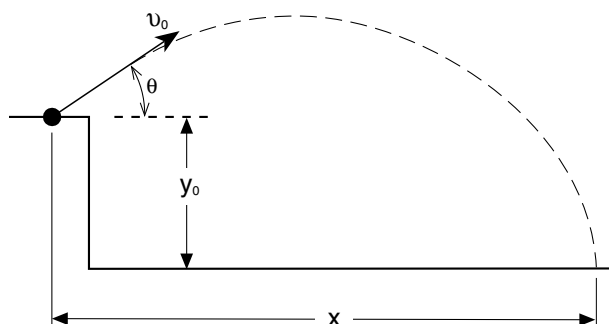
3. Put a ball into the Mini Launcher and cock it to the medium or long range setting.

• Note: In general, the experiment will not work as well on the short range setting because the muzzle speed is more variable with the change in angle.
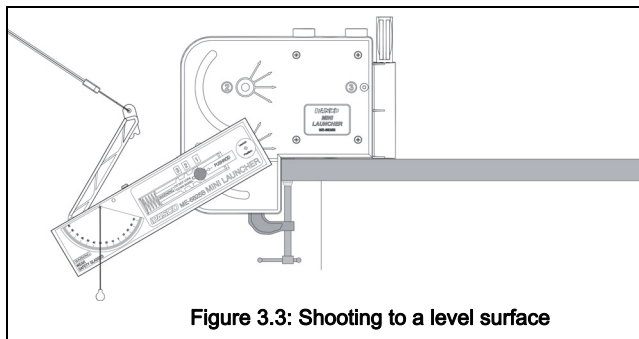
Figure 3.3: Shooting to a level surface

Procedure

Part A: 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. Tape a piece of carbon paper (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 measuring tape to measure the horizontal distance from the muzzle to the leading edge of the paper. (If a measuring tape is not available, use a plumb bob to find the point on the table that is directly beneath the release point on the barrel and measure the distance along the table from the muzzle to the leading edge of the paper.) Record the distance in the Data Table.

4. Carefully remove the carbon paper. Measure from the leading edge of the paper to each of the five dots and record these distances in the Data Table.

5. Increase the launch angle by 10 degrees and repeat all the steps. Keep the muzzle at the same elevation.

6. Keep repeating for angles up to and including 80 degrees (the complementary angle of 10 degrees).

Data Table: Part A

Table 1: Shooting to a Level Surface

	Angle	10	20	30	40	50	60	70	80
Horizontal Distance	1								
	2								
	3								
	4								
	5								
	Average								
	Paper distance								
	Total distance								

Part B: Shooting Off the Table

1. Turn the Mini Launcher so it will launch the ball to the floor.

2. Repeat the procedure and record the data in the Data Table.

Data Table: Part B

Table 2: Shooting off the Table

	Angle	10	20	30	40	50	60	70	80
Horizontal Distance	1								
	2								
	3								
	4								
	5								
	Average								
	Paper distance								
	Total distance								

Analysis

1. Find the average of the five distances in each case and record the results in the Data Tables.

2. Add the average distance to the distance from the Mini Launcher to the leading edge of the white paper to get the total distance (range) in each case. Record the results in the Data Tables.

3. For each Data Table, plot the range versus the angle and draw a smooth curve through the points.

Questions

1. From the graph, what angle give the maximum range for each case?

2. Is the angle for the maximum range greater or less for shooting off the table?

3. Is the maximum range further when the ball is shot off the table or on the level?

Notes

Exp. 4: Projectile Path

Equipment Needed

Item	Item
Mini Launcher and ball	Movable vertical target board*
Meter stick or measuring tape	Sticky tape
Graph paper	Carbon paper
White paper	

The target board should be as tall as the distance from the muzzle to the floor.

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, 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 launched horizontally, the time of flight of the projectile will be

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

The vertical distance, y, that the projectile falls during time, t, is given by

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

where g is the acceleration due to gravity. Substituting for t in the second equation gives

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

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

Setup

1. Clamp the Mini Launcher to a sturdy table or other horizontal surface. Mount the Launcher near one end of the table with the Launcher aimed away from the table.

2. Adjust the angle of the Mini Launcher to zero degrees so the ball will be launched horizontally.

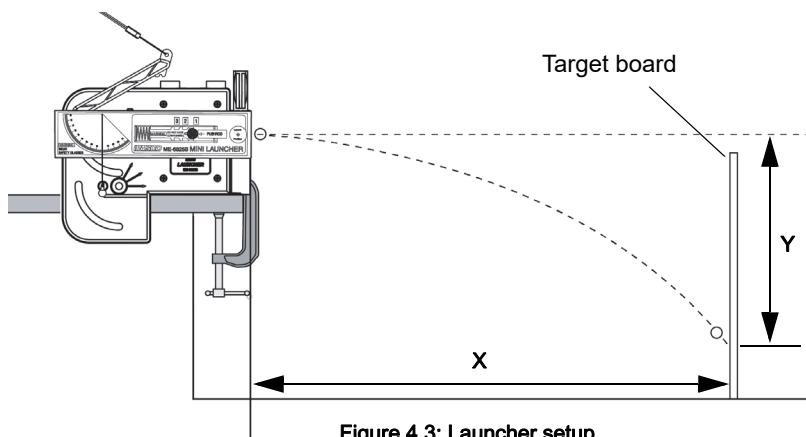3. Fire a test shot on medium range to determine the

Figure 4.3: Launcher setup

initial position of the vertical target board. Place the target board on the floor so that the ball hits the board near the bottom.

4. Cover the target board with white paper. Tape carbon paper over the white paper.

Procedure

1. Measure the vertical height from the floor to the muzzle and record the height in the Data Table. Mark this height on the target.

2. Measure the horizontal distance from the muzzle of the Mini Launcher to the target board and record it in the Data Table.

3. Shoot the ball.

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.

Data Table 4.1

Height of Muzzle = _____

Table 1: x, y Data

Horizontal (x)	Vertical (y)	x^2

Analysis

1. On the target board, measure the vertical distances from the muzzle level mark down to the ball marks and record them in Table 4.1.

2. Calculate x^2 for all the data points and record them in the Data Table.

3. Plot a graph of y versus x^2 and draw the best-fit light 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 the 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, *t*. Calculate the initial speed using this time and the horizontal distance, *x*. Record the results in Table 4.2.

7. Calculate the percent difference between the two initial speeds that were found using the different methods. Record the percent difference in Table 4.2. (To calculate the percent difference, let *A* be one of the initial speed values and let *B* be the other initial speed value.)

$$\left| \frac{A - B}{\left(\frac{A + B}{2} \right)} \right| x100$$

Data Table 4.2

Table 2: Compare Methods for Initial Speed

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

Question

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 of 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?

Notes

Exp. 5: Conservation of Energy

Equipment Needed

Item	Item
Mini Launcher and ball	Plumb bob and string
Meter stick or measuring tape	Sticky tape
White paper	Carbon paper
Smart Gate or Photogate Head (2) **optional***	Photogate Mounting Bracket ME-6821A **optional***

*Use a Smart Gate or two Photogates and Photogate Mounting Bracket with a PASCO Interface or Timer to measure the initial speed of the ball directly (see Experiment 2).

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.

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:

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

Figure 5.1: Conservation of Energy

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

$$GPE = mgh$$

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.

The initial speed of the projectile must be determined in order to calculate the initial kinetic energy. To calculate the initial speed, v_0, of a projectile fired horizontally, the horizontal distance travelled by the projectile is $x = v_0 t$ where t is the time that the projectile is in the air.

The vertical distance that projectile drops in time, t, is given by

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

The initial speed of the projectile can be calculated by measuring x and y and using y to calculate the time, t. The time of flight of the projectile can be found using
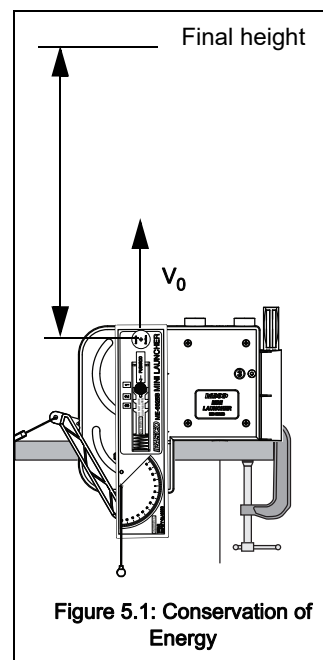
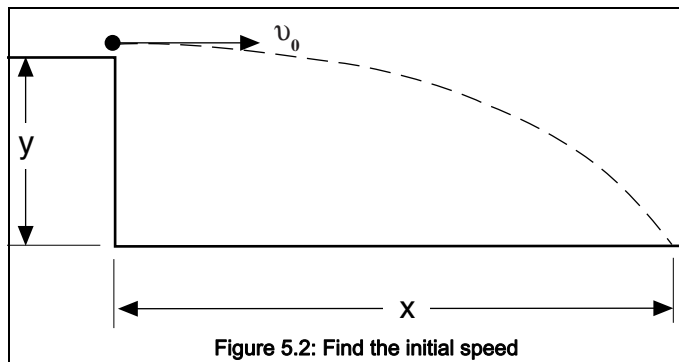$$t = \sqrt{\frac{2y}{g}}$$

Figure 5.2: Find the initial speed

and then the initial speed can be found using

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

Setup

1. Clamp the Mini Launcher to a sturdy table or other horizontal surface. Mount the Mini Launcher near one end of the table with the launcher aimed away from the table.

2. Point the Launcher straight up and fire a test shot on medium range to make sure that the ball doesn't hit the ceiling. (If it does, use the short range setting for this experiment or put 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 A: 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 that position, tape a piece of white paper to the floor. Place a piece of carbon paper (carbon-side down) on top of the white paper and tape it in place

• When the ball hits the carbon paper, it will leave a mark on the white paper.

2. Fire ten shots.

3. Measure the vertical distance from the bottom of the ball as it leaves the barrel to the floor. Record this distance in the Table 5.1. Use the distance to calculate the time of flight and record it.

4. Use a plumb bob to find the point on the floor that is directly beneath the release point on the barrel. Measure the horizontal distance along the floor from the release point to the leading edge of the piece of white paper. Record the distance in Table 5.1.

5. Carefully remove the carbon paper. Measure from the leading edge of the white paper to each of the ten dots and record these distances in Table 5.1.

6. Find the average of the ten distances and record it.

7. Using the horizontal distance and the time of flight, calculate the initial speed of the ball. Record the speed.

Data Table 5.1

Table 1:

Item	Value	Item	Value
Vertical distance		Calculated time of flight	
Horizontal distance to edge of paper		Initial speed	

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

Alternate Method for Determining the Initial Speed of the Ball (using photogates)

1. Attach a Photogate Mounting Bracket to the Mini Launcher and attach one Smart Gate or two Photogate Heads to the bracket. .

2. Plug the Smart Gate into a PASCO interface, or plug the two Photogate Heads into a PASCO interface or a timer.

3. Adjust the angle of the Launcher to 90 degrees (straight up).

4. Put a ball in the Mini Launcher and use the push-rod to cock it at the medium range setting.

5. Setup the software or the timer to measure the time between the ball blocking the Smart Gate or the two Photogate Heads.

6. Shoot the ball three times and calculate the average of these times. Record the data in the Table 5.2.

7. Calculate the initial speed of the ball based on the time and the distance. Record the value.

Table 5.2

Table 2: Initial Speed Using Photogates

Trial	Time
1	
2	
3	
Average Time	
Initial Speed	

Part B: Measure the Height of the Ball

1. Adjust the angle of the Mini Launcher to 90 degrees (straight up).

2. Shoot the ball on the medium range setting several times and then measure the maximum height attained by the ball. Record the maximum height in Table 5.3.

3. Determine the mass of the ball and record it in Table 5.3.

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

$$\left| \frac{KE - GPE}{\frac{KE + GPE}{2}} \right| x100$$

Table 3: Results

Item	Value
Maximum height of ball	
Mass of ball	
Initial Kinetic Energy	
Final Potential Energy	
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?

Exp. 6: Conservation of Momentum

Equipment Needed

Item	Item
Mini Launcher and 2 balls	2-D Collision Accessory
Meter stick or measuring tape	Sticky tape
White paper, large sheet	Carbon paper (2 or 3 sheets)
Protractor	Plumb bob and string

Purpose

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

Theory

A ball is shot toward another ball that is initially at rest, resulting in a collision after which the two balls move in different directions. In the system consisting of just the 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.

(a) before collision   (b) after collision

Figure 6.1: Conservation of Momentum

Before collision, since all the momentum is in the direction of Ball #1 (m_1), it is convenient to define the x-axis in this direction. Momentum before the collision is:

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

where v_0 is the initial speed of Ball #1 and $\hat{x}$ is the unit vector in the x-direction. The momenta of the two balls after the collision consists of both horizontal and vertical components, so the momentum after the collision is:

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

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

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, t

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

Equating the momentum in the x-direction before the collision to the momentum in the x-direction after the collision gives:

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

In a perfectly elastic collision, kinetic energy is conserved as well as momentum.

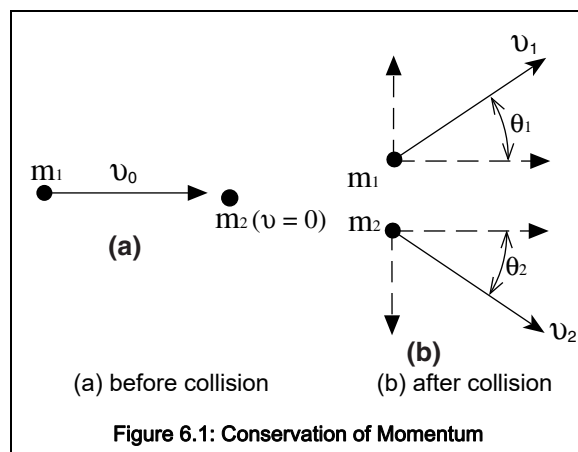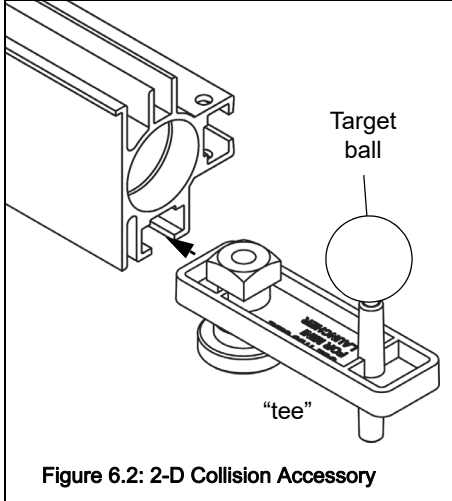$$\frac{1}{2}m_1 v_0^2 = \frac{1}{2}m_1 v_1^2 + \frac{1}{2}m_2 v_2^2$$

Also, when energy is conserved, the paths of two balls of equal mass will be at right angles to each other after the collision.

Setup

1. Clamp the Mini Launcher to a sturdy table near one end of the table with the barrel aimed inward toward the table. Mount the Mini Launcher in the upper position on the stand.

   • In this position, the Mini Launcher will launch the ball horizontally onto the table.

2. Cover the table with white paper (such as butcher paper). NOTE: The paper must reach the base of the Launcher.

3. 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 (carbon-side down) over the spot where the ball lands.

Figure 6.2: 2-D Collision Accessory

4. Mount the 2-D Collision Accessory to the front of the Mini Launcher. Put a target ball on the post ("tee") of the accessory.

5. Loosen the thumbscrew and rotate the 2-D Collision Accessory slightly to one side.

   • The "tee" must be located 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.

   • Tighten the thumbscrew to hold the accessory in place.

6. Load the Mini Launcher and fire a test shot to check that both balls hit the table at the same time. Tape a piece of carbon paper on the white paper at each spot where the two balls land on the table.

Procedure

A. No Collision

1. Put "ball 1" into the Mini Launcher and cock it to the short range setting. Do not put a target ball on the "tee".

2. Shoot the ball straight ahead and repeat the procedure five times.

B. Elastic Collision

1. Use two balls. Load Ball 1 into the Mini Launcher at the short range setting. Place Ball 2 on the "tee" of the 2-D Collision Accessory.

2. Shoot Ball 1 so it collides with the target ball (Ball 2). Repeat the procedure five times.

C. Inelastic Collision

1. Use two balls. Load Ball 1 into the Mini Launcher at the short range setting. Put a small loop of sticky tape (sticky-side out) on Ball 2 and place it on the "tee".

2. Orient the tape side of Ball 2 so that it will be struck by the launched ball (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.

4. Shoot Ball 1 and if the two balls stick together but miss the carbon paper, relocate the carbon paper and shoot once more.

•   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 on the paper the spot directly below the point of contact of the two balls. Mark this spot on the paper as the "point-of-contact" spot. Carefully remove the carbon paper from the white paper.

Analysis

The time of flight for each shot is the same because the vertical distance for each shot is 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.

A. No Collision

1. Draw straight lines from the "point-of-contact" spot to each of the dots made by the 'no collision' shots.

2. Measure each straight line and record the length. Find the average of the five lengths and record the length as the "initial x-momentum" in Table 6.1 and Table 6.2. (For example, if the length is 65 cm, record "65" as the value for the "initial x-momentum" but do not include any units.)

B. Elastic Collision

1. Draw a straight line from the "point-of-contact" through the *center* of the group of 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 'elastic collision' shots. (There should be five lines on each side of the center line.)

3. Measure from the "point-of-contact" to each of the dots made by Ball 1. Find the average of the five lengths. Draw a straight line from the "point-of-contact" through the center of the group of dots made by Ball 1.

4. Measure the angle from the centerline to the straight line for Ball 1. Use this angle and the average length of the line for Ball 1 to calculate the x-component for Ball 1 and the y-component for Ball 1. Record the values.

5. Measure from the "point-of-contact" to each of the dots made by Ball 2. Find the average of the five lengths. Draw a straight line from the "point-of-contact" through the center of the group of dots made by Ball 2.

6. Measure the angle from the centerline to the straight line for Ball 2. Use this angle and the average length of the line for Ball 2 to calculate the x-component for Ball 2 and the y-component for Ball 2. Record the values.

7. Add the x-momentum for Ball 1 and the x-momentum for Ball 2 and record the result in Table 6.1 as "Final x-momentum".

8. Calculate the initial kinetic energy of Ball 1 and the sum of the kinetic energy of Ball 1 and Ball 2 after the collision.

9. Calculate the percent differences.

Table 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		

C. Inelastic Collision

1. Draw straight lines from the "point-of-contact" spot to the dots made by the 'inelastic collision' shot. (There should be two lines.)

2. Measure from the "point-of-contact" to each of the dots made by the 'inelastic collision' shot.

3. Measure the angle from the centerline to the straight line for each dot of the 'inelastic collision' shot.

4. Use the angle and the length of the lines for the shot to calculate the x-component and the y-component for each ball in the 'inelastic collision' shot. Record the values.

5. After the collision, add the x-momentum for Ball 1 and the x-momentum for Ball 2 and record the result in Table 6.1 as "Final x-momentum".

6. Calculate the initial kinetic energy of Ball 1 and the sum of the kinetic energy of Ball 1 and Ball 2 after the collision.

7. Calculate the percent differences.

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?

Exp. 7: Vary the Angle to Maximize the Height

Equipment Needed

Item	Item
MIni Launcher and ball	Board to protect wall
Meter stick or measuring tape	Sticky tape
White paper, large sheet	Carbon paper (several sheets)
Plumb bob and string	

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 the ball is shot at an angle at a fixed distance, x, from a target such as a vertical wall, the ball hits the wall at a height y given by:

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

where y_0 is the initial height of the ball, v_0 is the initial speed of the ball as it leaves the muzzle, θ is the angle of inclination above horizontal, g is the acceleration due to gravity, and t is the time of flight. The range is the horizontal distance, x, between the muzzle of the Launcher and the place where the ball hits, given by

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

Solving this equation for the time of flight, t, gives

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

Figure 7.1: Maximizing Height

Substituting for t in the equation for y gives

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

To find the angle, θ, that gives the maximum height, y, find the first derivative of the equation for y and set it equal to zero. Solve for the angle, θ.

$$\frac{dy}{d\theta} = x\sec^2\theta - \frac{gx^2 \tan\theta \sec^2\theta}{v_0^2} = 0$$

Solving for the angle, θ, gives:

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

Since the second derivative is negative for θ_{max}, the angle is a maximum. To find the inital 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 for y_{max}, θ_{max}, and x.
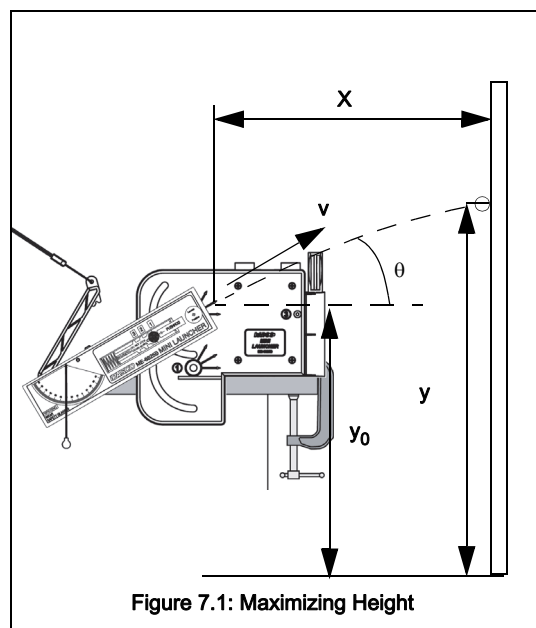
Setup

1. Clamp the Mini Launcher to a sturdy table near one end of the table. Mount the barrel in the upper position with the muzzle aligned with the upper pivot hole. Aim the barrel toward a wall about 2 meters from the table.

2. Use a vertical board to the protect the wall and cover the board with white paper.

3. Fire a test shot to see where the ball hits the board and tape a piece of carbon paper (carbon-side down) at that position.

Procedure

1. Shoot the ball at various angles and pinpoint 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 the Data Table.

4. Measure the horizontal distance from the muzzle to the vertical board and record the value.

5. Measure the initial height of the ball where it leaves the muzzle and record the value.

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.

Table 1: Data and Results

Item	Value
Measured Angle for Maximum Height	
Maximum Height	
Horizontal Distance	
Initial Height	
Calculated Initial Speed	
Calculated Angle for Maximum Hight	
Percent Difference between Angles	

2. Calculate the angle for maximum height using the initial speed calculated in step 1 and the horizontal distance from the wall to the launcher.

3. Calculate the percent difference between the measured angle and the calcuulated angle. (Let A be one of the angles and B be the other angle).

$$Difference = \left| \frac{A - B}{\frac{A + B}{2}} \right| x100$$

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 be height be maximized for a launch angle of 45°? What would the maximum height be in this case?

Exp. 8 (Demo): Do 30° and 60° Give the Same Range?

Equipment Needed

Item
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 place where the projectile lands, given by $x = (v_0\ cos\ \theta)\ t$ where v_0 is the initial speed of the ball as it leaves the muzzle, θ is the launch angle above 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 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.

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

where g is the acceleration due to gravity. Substituting for t in the equation for x gives:, and t is the time

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

of flight. and using a trigonometry identity gives:

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

The ranges for the angles 30° and 60° are the same since sin 60° = sin 120°.

Setup

1. Clamp the Mini Launcher to a sturdy table with the barrel mounted in the lower position on the stand. Mount the launcher near one end of the table with it aimed toward the middle of the table.

Figure 8.1: Set up to shoot on level surface.

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. Put the ball into the Mini Launcher and cock it to the medium range or long range setting.

•   NOTE: In general, this demonstration will not work as well on the short range setting because the muzzle speed 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. Call attention to the fact that the ball again lands on the 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 question: 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°.

Exp. 9 (Demo): Simultaneous Shots at Different Speeds

Equipment Needed

Item
Mini Launcher (2) and ball (2)

Purpose

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

Theory

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, travelled by the projectile depends on the initial speed, v_0, and the time of flight, t. The distance $x = v_0 t$.

The time of flight depends on the vertical distance that the projectile falls.

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

where g is the acceleration due to gravity. Since the vertical distance is the same fore each projectile, the time of flight is the same for each projectile.

Setup

1. Clamp two Mini Launchers adjacent to each other on a sturdy table. Mount the Mini Launchers near one end of the table with the Launchers aimed away from the table so the balls will land on the floor.

2. Adjust the angle of each Mini Launcher to 0° so the balls will fire horizontally.

Figure 9.1: Shots fired simultaneously
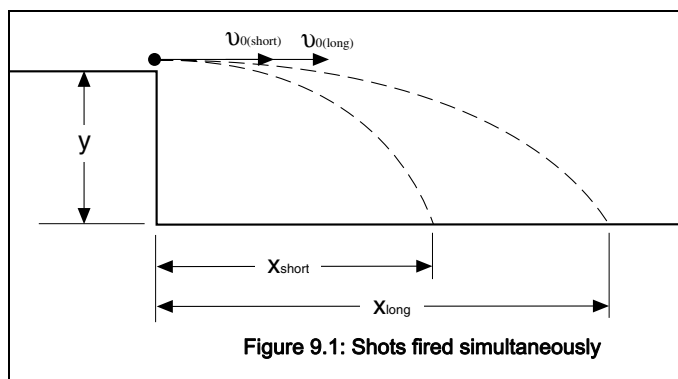
Procedure

1. Put a ball into each Mini Launcher. Cock one Mini Launcher to the short range setting and cock the other Mini Launcher to the long range setting.

2. Ask the class to be quiet and listen for the balls striking the floor.

• NOTE: If there is only one click, that means that the balls hit the floor simultaneously.

3. Put 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 class if they heard one click or two.

Exp. 10 (Demo): Shooting Through Hoops

Equipment Needed

Item	Item
Mini Launcher and ball	Ring clamp on stand (5)
Smart Gate **OR** Photogate Head (2) **optional**	Photogate Mounting Bracket **optional**
PASCO Interface and Software **OR** Smart Timer	
Meter stick	Two-meter stick

Purpose

The purpose of this demonstration is to confirm that the part of a projectile is parobolic.

Theory

The range is the horizontal distance, x, between the muzzle of a Mini Launcher and the place where the projectile hits, 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. The vertical position, y, of the projectile at time t is given by:

$$y = y_0 - \left(\frac{1}{2}\right) g t^2$$

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 the expression in the y-equation gives:

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

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

Pre-Lab

Before the demonstration begins, find the initial speed of the ball.

- Attach a Photogate Mounting Bracket to the Mini Launcher. Use a Smart Gate with a PASCO Interface or two Photogate Heads with an interface or a Smart Timer to measure the initial speed of the ball.

- Alternatively, shoot the ball horizontally and measure x and y. (Use y to calculate the time of flight. See experiments 1 and 2.)

Setup

1. Clamp the Mini Launcher to a sturdy table near one end of the table with the Launcher aimed away from the table so the ball will land on the floor.

2. Adjust the angle of the Launcher to 0° so the ball will fire 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.

Table 1: X- and y-positions

t (sec)	x = v_0t (cm)	y = y_0 - (1/2)gt^2 (cm)
0.1		
0.2		
0.3		
0.4		
0.5		

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 class: What shape of curve is formed by the rings? What is the path of the projectile?

Figure 10.1: Demonstration setup
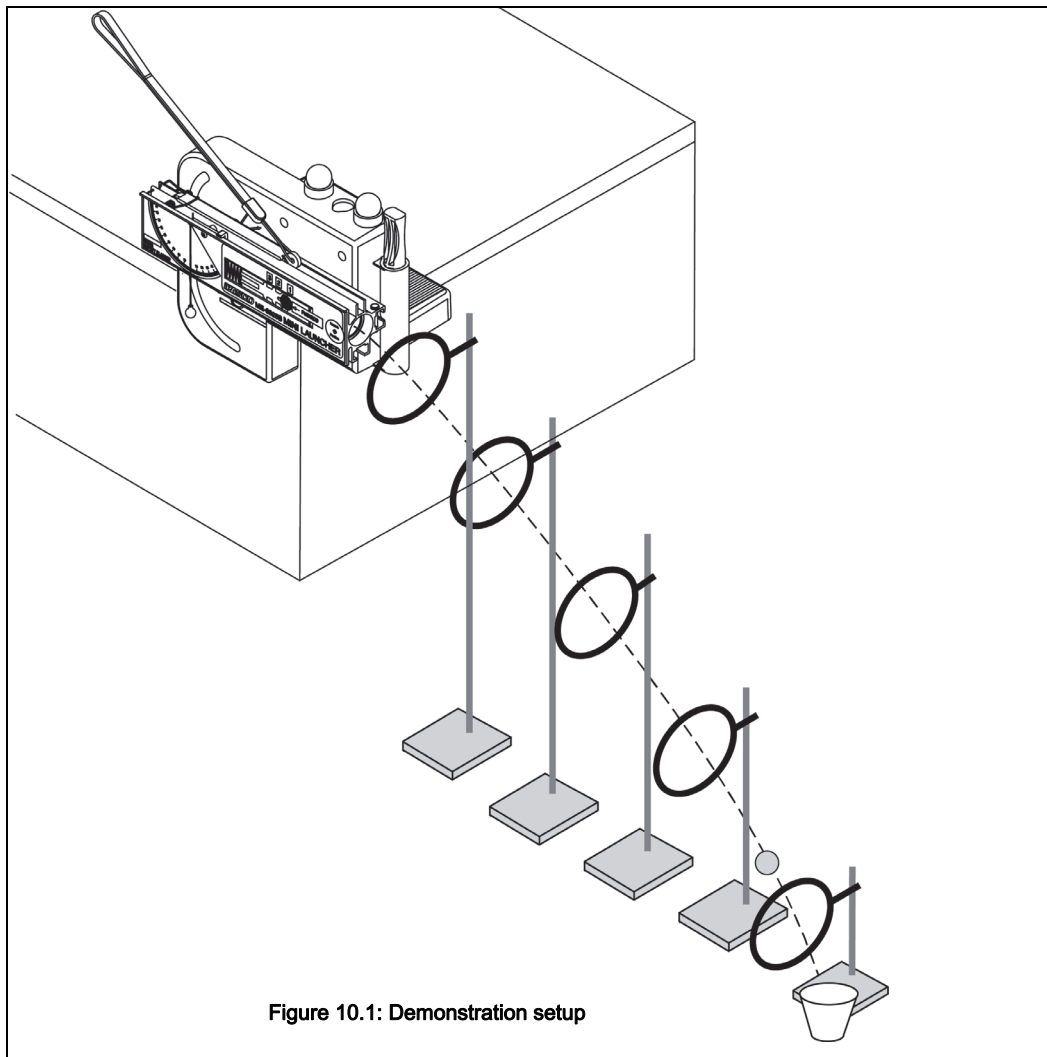
Technical Support

For assistance with any PASCO product, contact PASCO at:

Address: PASCO scientific
             10101 Foothills Blvd.
             Roseville, CA 95747-7100

Phone: +1 916 462 8384 (worldwide)
             800-772-8700 (U.S.)

Web: www.pasco.com

Email: support@pasco.com

For more information about the Mini Launcher and the latest revision of this Instruction Manual, visit the PASCO web site and enter ME-6825 into the Search window.