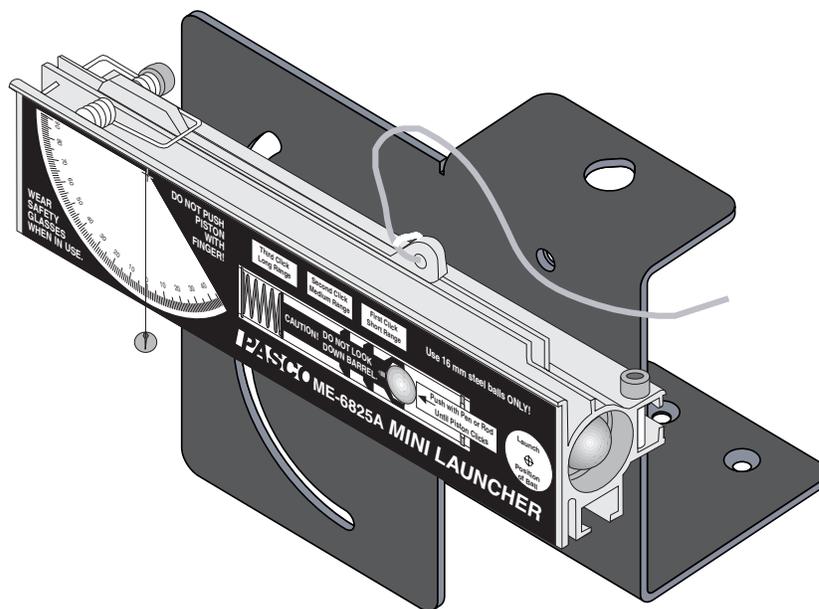


**Instruction Manual and  
Experiment Guide for  
the PASCO scientific  
Model ME-6825A**

012-09562A

# **MINI LAUNCHER**



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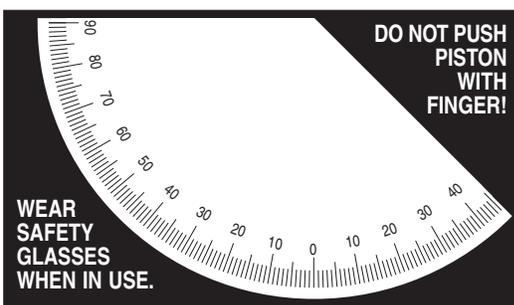
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## Introduction

The PASCO Mini Launcher has been designed for projectile experiments and demonstrations. The only additional equipment required is a C-clamp or ME-9376B Universal Table Clamp for clamping the Launcher to a table. The features of the Mini Launcher include:

- LAUNCH AT ANY ANGLE Between  $-45^\circ$  and  $90^\circ$ :

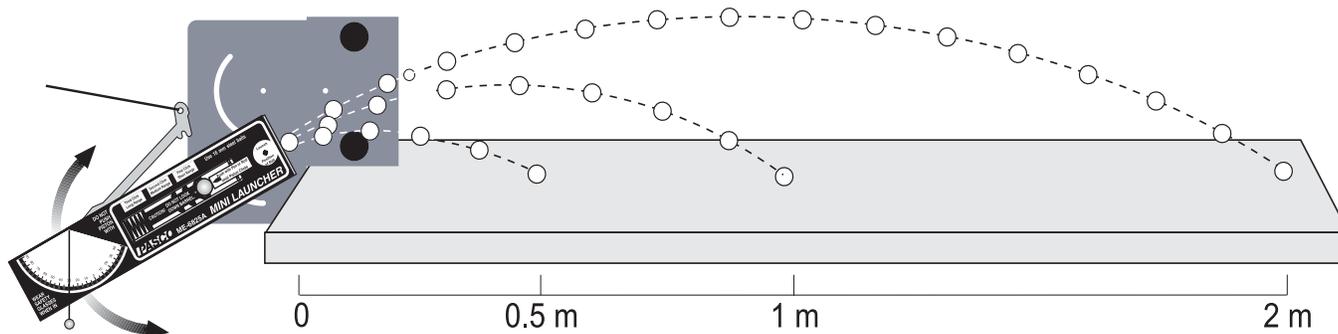
Balls can be launched at any angle from 0 to 90 degrees measured above the horizontal. The magnetic piston holds the steel ball in position for launch at any angle from 0 to 45 degrees measured below the horizontal.



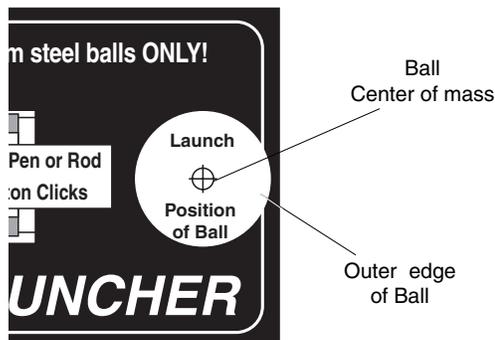
The angle is easily adjusted using the thumb screw. The built-in protractor and plumb bob on the side of the launcher give a convenient and accurate way of determining the angle of inclination.

- 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.



- FIXED ELEVATION INDEPENDENT OF ANGLE:



The Mini Launcher can be mounted so that it pivots at the muzzle end. 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 ME-9376B Universal Table Clamp (not included) so there is very little recoil. The trigger is pulled with a string to minimize jerking.

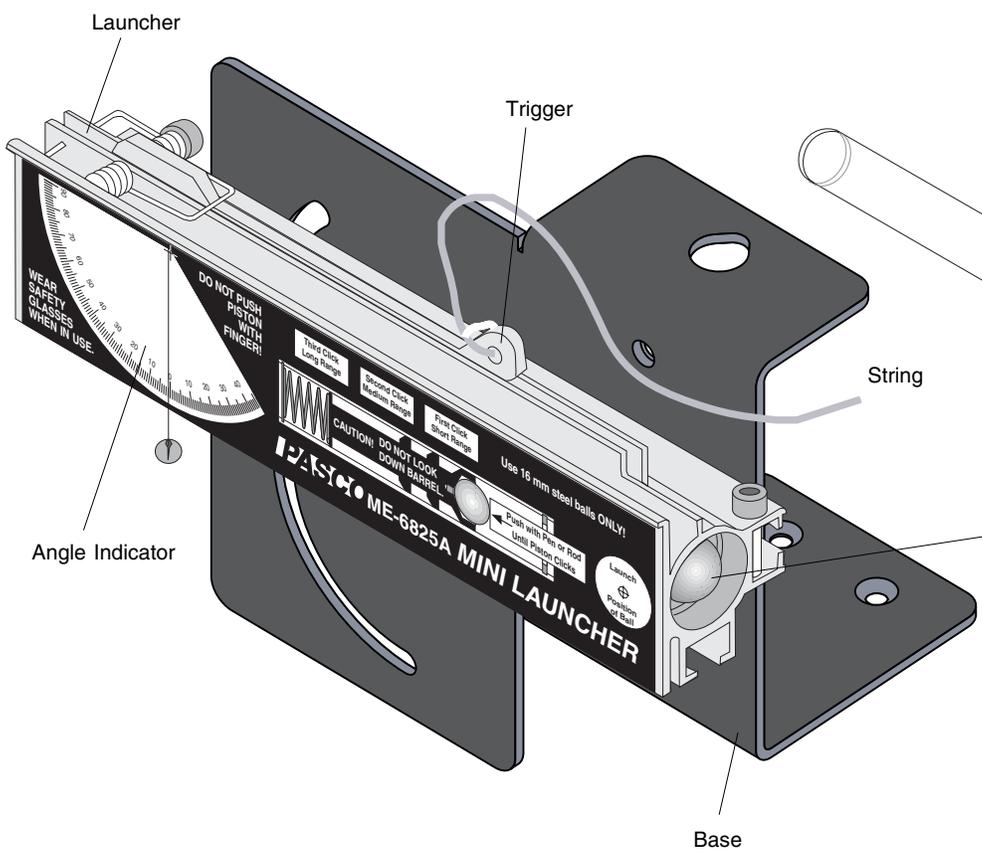
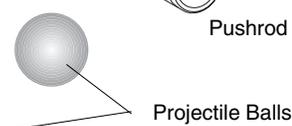
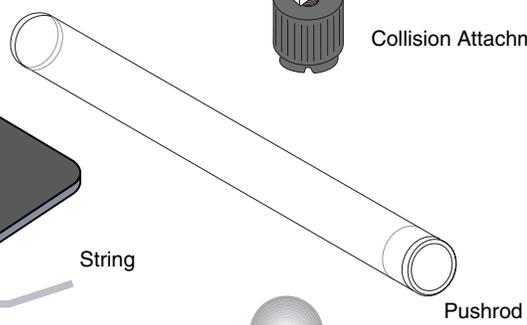
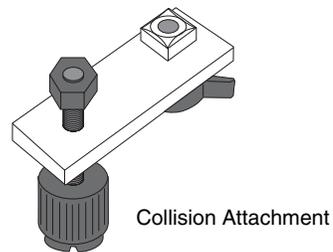
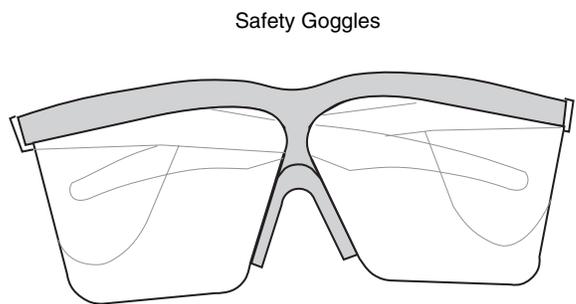
- COMPUTER COMPATIBLE:

Photogates may be attached with the accessory bracket (ME-6821A) to connect the Mini Launcher to a computer to measure the muzzle speed. Also a photogate at the muzzle and the Time of Flight accessory (ME-6810) can be used to time the flight of the ball.

# Equipment

The ME-6825 Mini Launcher includes the following:

- Launcher and Base (Assembled)
- (2) 16mm Steel Balls
- String (to pull trigger)
- Collision Attachment
- Safety Goggles
- Pushrod
- Manual



## General Operation of the Mini Launcher

### ① 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!

- Tie the string to the trigger before loading.
- The base of the Mini Launcher can be clamped to the edge of a table using the clamp of your choice. When shooting onto the floor, it is desirable to have the label side of the Launcher even with one edge of the table so a plumb bob can be used to locate the position of the muzzle with respect to the floor. See page 6 for mounting options.
- The Mini Launcher can be mounted to shoot onto the table such that the launch position of the ball is at the same height as the table.

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

### ② Aim

- The angle of inclination is adjusted by loosening the thumb screws and rotating the Launcher to the desired angle above or below the horizontal as indicated by the plumb bob and protractor on the side of the Launcher. When the angle has been selected, tighten the thumb screw.

- To help align the launcher with a target, use a straight edge or meter stick against the lip on the launcher barrel as illustrated.

### ③ Load

- Always cock the launcher with the ball in the piston.

**NOTE:** Use only 16 mm steel balls with the Mini Launcher.

- Place the ball in the barrel. Push the ball down the barrel with the pushrod until the trigger catches the piston. One audible click indicates that the piston is cocked in the shortest range setting, two clicks indicate the medium range and three clicks set the piston on the long range setting.



- Remove the pushrod.

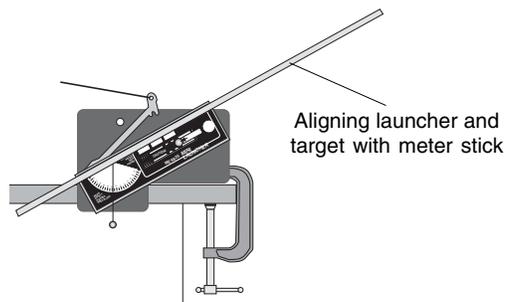
**CAUTION:** Do not push the piston with your finger. Your knuckle may get stuck.

### ④ Shoot

- Before launching the ball, make certain that no person is in the way.
- To shoot the ball, pull straight up on the string that is attached to the trigger. It is only necessary to pull it about a centimeter.

### ⑤ Storage

- Store the Launcher with the spring uncompressed.



# Installing the Optional Photogate Bracket (ME-6821)

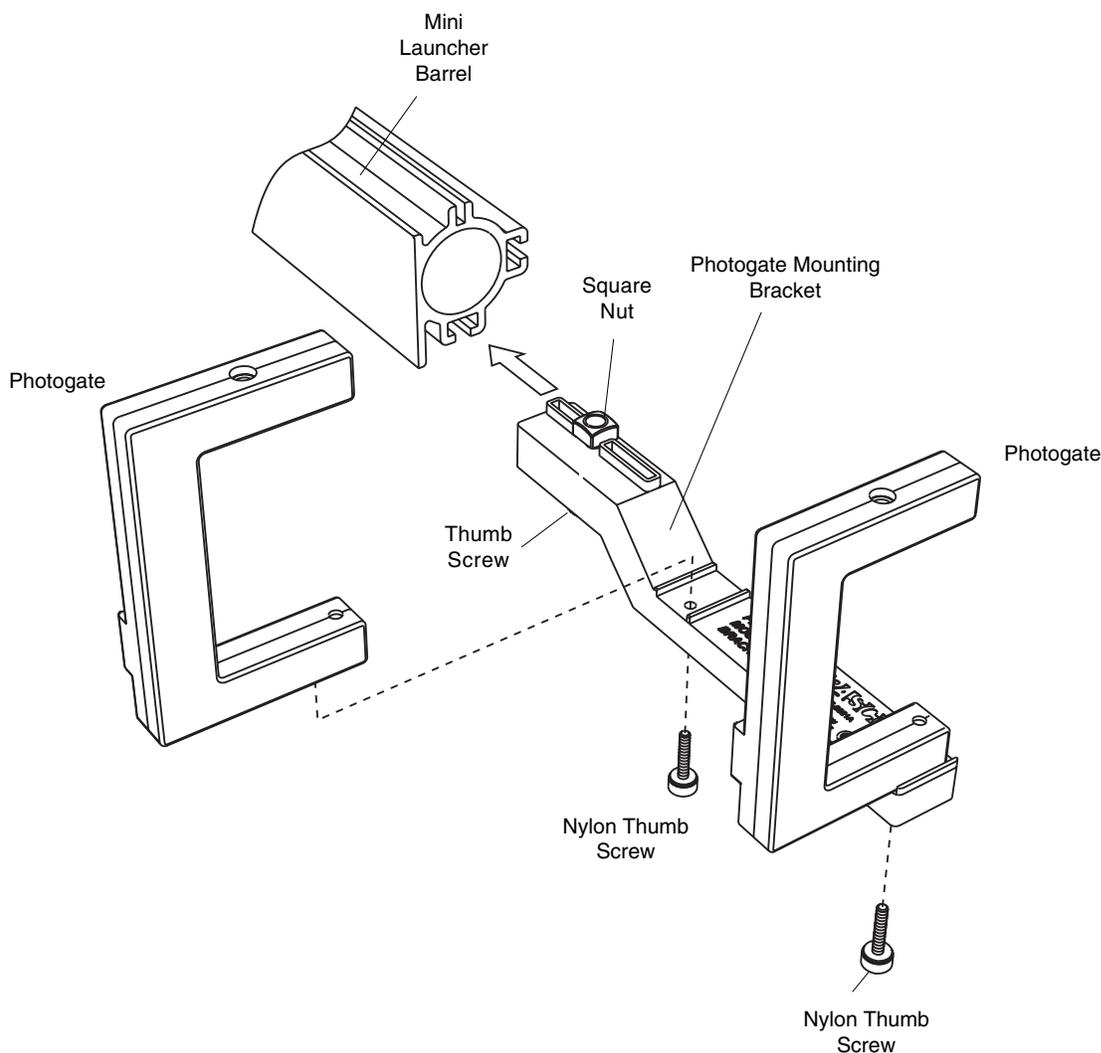
The Photogate Bracket is an optional accessory for mounting one or two photogates on the Mini Launcher to measure the muzzle velocity of the ball.

Installation is as follows:

- ① Prepare the bracket by inserting the thumb screw through the hole in the bracket near the end and start the square nut onto the end of the thumb screw (see diagram).

Attach the photogates to the bracket using the remaining holes in the bracket and the screws provided with the photogates.

- ② To mount the bracket to the Launcher, align the square nut in the slot on the bottom of the Launcher and slide the nut into the slot. Slide the bracket back until the photogate nearest to the barrel is as close to the barrel as possible without blocking the beam. Tighten the thumb screw to secure the bracket in place.
- ③ When storing the Mini Launcher, the photogate bracket need not be removed. It can be slid back along the barrel with or without the photogates in place, making as compact a package as possible.



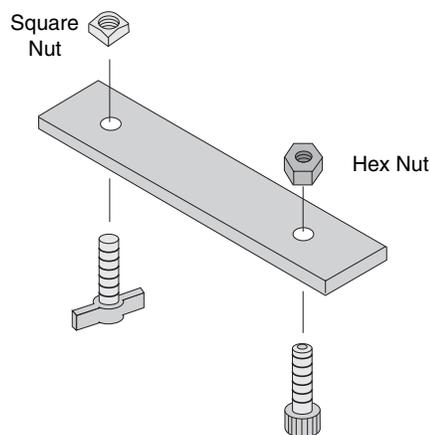
## Installing the 2-Dimensional Collision Attachment

The two dimensional Collision Attachment consists of 2 screws, 2 nuts, and a flat plastic bar. It is used with the Mini Launcher to hold a second ball in front of the muzzle so the launched ball will collide with the second ball, creating a 2-dimensional collision.

### Assembly

To assemble the collision attachment, insert the screws through the holes and secure with the nuts as shown in the following illustration.

To mount the collision attachment to the Launcher the square nut slides into the T-shaped channel on the bottom of the Launcher. (See Experiment Figure 6.2)

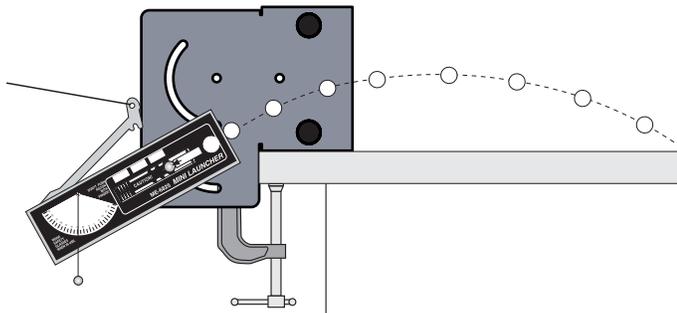


## Expectations for the Mini Launcher

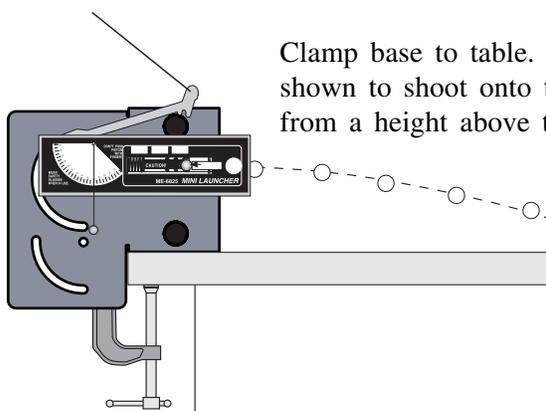
The following are helpful hints and approximate values you may find useful:

- ① The muzzle speed will vary slightly with angle. The difference between muzzle speed when shot horizontally versus vertically can be anywhere from zero to 8%, depending on the range setting and the particular launcher.
- ② The scatter pattern is minimized when the Mini Launcher base is securely clamped to a sturdy table. Any wobble in the table will show up in the data.
- ③ The angle of inclination can be determined to within one-half of a degree.

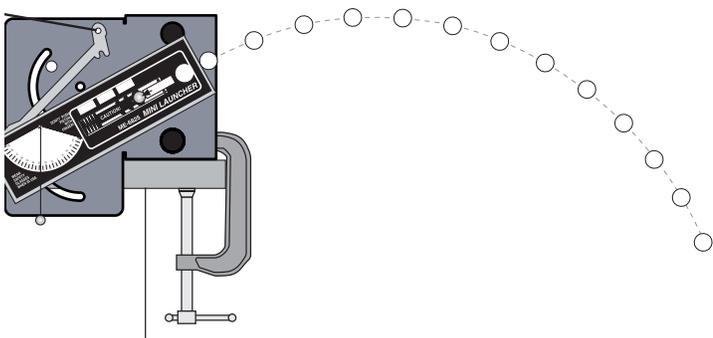
# Launch Positions



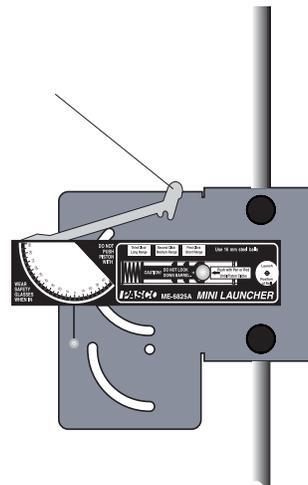
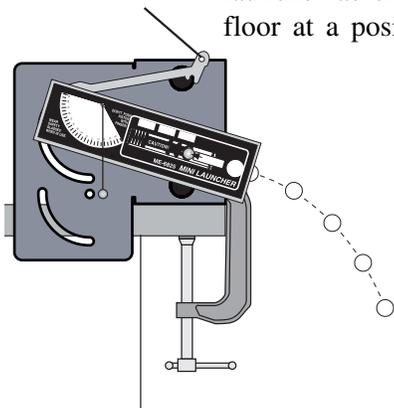
Clamp base to table. Mount launcher as shown to shoot onto table. The square nut that the Launcher pivots around should be slid to the front of the launcher. Ball is launched at table level. When you change the angle of the launcher, the launch position does not change.



Clamp base to table. Mount launcher as shown to shoot onto table. Ball is launched from a height above table level.

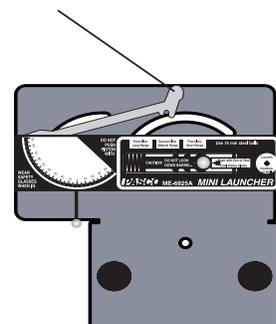


Clamp base to side edge of table. Mount launcher as shown to shoot off table onto floor at a positive or negative angle.



Clamp base to a vertical rod.

Place base on a tabletop or floor and hold it with your hand.



## Experiment 1: Projectile Motion

### EQUIPMENT NEEDED:

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

### Purpose

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

### Theory

To predict where a ball will land on the floor when it is shot off a table at an angle, it is necessary to first determine the initial speed (muzzle velocity) of the ball. This can be determined by launching the ball horizontally off the table and measuring the vertical and horizontal distances through which the ball travels. Then the initial velocity can be used to calculate where the ball will land when the ball is shot at an angle.

#### INITIAL HORIZONTAL VELOCITY:

For a ball launched horizontally off 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. Air friction is assumed to be negligible.

The vertical distance the ball drops in time  $t$  is given by  $y = v_0 (\sin \theta) t - \frac{1}{2} g t^2$ .

The initial velocity of the ball can be determined by measuring  $x$  and  $y$ . The time of flight of the ball can be found using:

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

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

#### INITIAL VELOCITY AT AN ANGLE:

To predict the range,  $x$ , of a ball launched with an initial velocity at an angle,  $\theta$ , above the horizontal, first predict the time of flight using the equation for the vertical motion:

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

where  $y_0$  is the initial height of the ball and  $y$  is the position of the ball when it hits the floor. Then use  $x = (v_0 \cos \theta) t$  to find the range. If the ball is shot at an angle below the horizontal, then  $\theta$  is negative.

### Setup

- ① Clamp the Mini Launcher near one end of a sturdy table as shown in Figure 1.1.
- ② Adjust the angle of the Mini Launcher to zero degrees so the ball will be shot off horizontally.

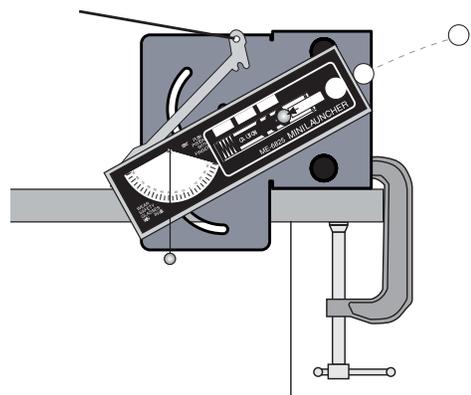


Figure 1.1: Setup to shoot horizontally off table

**Procedure**

**Part A: Determining the Initial Velocity of the Ball**

- ① Put the ball into the Mini Launcher and cock it to the long range position. Fire one shot to locate where the ball hits the floor. At this position, tape a piece of white paper to the floor. Place a piece of carbon paper (carbon-side down) on top of this paper and tape it down. When the ball hits the floor, it will leave a mark on the white paper.
- ② Fire about ten shots.
- ③ Measure the vertical distance from the bottom of the ball as it leaves the barrel (this position is marked on the side of the barrel) to the floor. Record this distance in Table 1.1.
- 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 paper. Record in Table 1.1.
- ⑤ Measure from the leading edge of the paper to each of the ten dots and record these distances in Table 1.1.
- ⑥ Find the average of the ten distances and record the value in Table 1.1.
- ⑦ Using the vertical distance and the average horizontal distance, calculate the time of flight and the initial velocity of the ball. Record in Table 1.1.
- ⑧ Calculate the Total Average Distance. Record in Table 1.1.

**Table 1.1 Determining the Initial Velocity**

Vertical distance = \_\_\_\_\_ Horizontal distance to paper edge = \_\_\_\_\_  
 Calculated time of flight = \_\_\_\_\_ Initial velocity = \_\_\_\_\_

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

(Total Average Distance = Distance to paper edge + Average Distance)

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

- ① Adjust the Mini Launcher to launch at an angle between 20 and 60 degrees above the horizontal. Record this angle in Table 1.2.
- ② Using the initial velocity and vertical distance found in the first part of this experiment, calculate the new time of flight and the new horizontal range for a projectile launched at the new angle. Record in Table 1.2.
- ③ 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 from the Mini Launcher. Cover the paper with carbon paper.
- ④ Shoot the ball ten times.
- ⑤ Measure the ten distances and take the average. Record in Table 1.2.

### **Analysis**

- ① Calculate the Total Average Distance. Record in Table 1.2.  
(Total Average Distance = Distance from Edge of Paper + Horizontal Distance to paper edge)
- ② Calculate and record the percent difference between the predicted value and the resulting average distance when shot at an angle.
- ③ Estimate the precision of the predicted range. How many of the final 10 shots landed within this range?

**Table 1.2 Confirming the Predicted Range**

Angle above horizontal = \_\_\_\_\_ Horizontal distance to paper edge = \_\_\_\_\_

Calculated time of flight = \_\_\_\_\_ Predicted Range = \_\_\_\_\_

Trial Number	Distance from Edge of Paper
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Total Average Distance	

**Part C: Predicting the Range of the Ball Shot at a Negative Angle**

- ① Adjust the Mini Launcher to launch at an angle between 10 and 40 degrees below the horizontal and record this angle in Table 1.3.
- ② Using the initial velocity and vertical distance found in the first part of this experiment, calculate the new time of flight and the new horizontal range for a projectile launched at the new angle. Record in Table 1.3.
- ③ 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 from the Mini Launcher. Cover the paper with carbon paper.
- ④ Shoot the ball ten times.
- ⑤ Measure the ten distances and take the average. Record in Table 1.3.

**Analysis**

- ① Calculate the Total Average Distance. Record in Table 1.3.  
(Total Average Distance = Distance from Edge of Paper + Horizontal Distance to paper edge)
- ② Calculate and record the percent difference between the predicted value and the resulting average distance when shot at an angle.
- ③ Estimate the precision of the predicted range. How many of the final 10 shots landed within this range?

**Table 1.3 Confirming the Predicted Range**

Angle below horizontal = \_\_\_\_\_      Horizontal distance to paper edge = \_\_\_\_\_  
 Calculated time of flight = \_\_\_\_\_      Predicted Range = \_\_\_\_\_

Trial Number	Distance from Edge of Paper
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Total Average Distance	

## **Experiment 2: Projectile Motion Using Photogates**

### **EQUIPMENT NEEDED**

- |   |   |
|---|---|
| <ul style="list-style-type: none"> <li>– Mini Launcher and steel ball</li> <li>– (2) Photogates</li> <li>– Plumb bob</li> <li>– Carbon paper</li> </ul> | <ul style="list-style-type: none"> <li>– Photogate bracket</li> <li>– Computer and Timing software</li> <li>– Meter stick</li> <li>– White paper</li> </ul> |
|---|---|

### **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 velocity of the ball.

### **Theory**

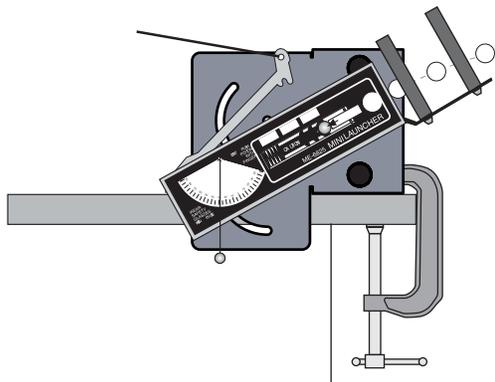
To predict where a ball will land on the floor when it is shot off a table at an angle, it is necessary to first determine the initial speed (muzzle velocity) of the ball. This can be determined by shooting the ball and measuring the speed using photogates. To predict the range,  $x$ , of the ball when it is launched with an initial velocity at an angle  $\theta$ , above the horizontal, first predict the time of flight using the equation for the vertical motion:

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

where  $y_0$  is the initial height of the ball and  $y$  is the position of the ball when it hits the floor. Then use  $x = (v_0 \cos\theta) t$  to find the range. If the ball is shot at an angle below the horizontal,  $\theta$  is negative.

### **Setup**

- ① Clamp the Mini Launcher near one end of a sturdy table as shown in Figure 2.1.
- ② Adjust the Mini Launcher to launch either at an angle between 20 and 60 degrees above the horizontal, or 10 to 40 degrees below.
- ③ Attach the photogate bracket to the Launcher and attach two photogates to the bracket. Plug the photogates into a computer or other timer.



**Figure 2.1: Setup to determine initial velocity**

**Procedure**

***PART A: Determining the Initial Velocity of the Ball***

- ① Put the steel ball into the Mini Launcher and cock it to the long range position.
- ② Run the timing program and set it to measure the time it takes the ball to pass through both photogates.
- ③ Shoot the ball three times and take the average of these times. Record in Table 2.1.
- ④ Calculate the initial speed of the ball and record it in Table 2.1. The distance between the photogates is 10 cm.

**Table 2.1 Initial Speed**

Angle above or below horizontal = \_\_\_\_\_

Trial Number	Time
1	
2	
3	
Average Time	
Initial Speed	

***PART B: Predicting the Range of the Ball Shot at an Angle***

- ① Keep the angle of the Mini Launcher at the selected angle.
- ② Measure the vertical distance from the bottom of the ball as it leaves the barrel (this position is marked on the side of the barrel) to the floor. Record this distance in Table 2.2.
- ③ Using the initial velocity and vertical distance found in Part A, calculate the time of flight and the horizontal range for a projectile launched at the selected angle. Record in Table 2.2.
- ④ 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 from the Mini Launcher. Cover the paper with carbon paper.
- ⑤ Shoot the ball ten times.
- ⑥ Measure the ten distances and take the average. Record in Table 2.2.

**Table 2.2 Confirming the Predicted Range**

Angle above or below horizontal = \_\_\_\_\_

Horizontal distance to paper edge = \_\_\_\_\_

Calculated time of flight = \_\_\_\_\_

Predicted Range = \_\_\_\_\_

Trial Number	Distance from Edge of Paper
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Average	
Total Average Distance	

### Analysis

- ① Calculate the Total Average Distance. Record in Table 2.2.  
(Total Average Distance = Distance from Edge of Paper + Horizontal Distance to paper edge)
- ② Calculate the percent difference between the predicted value and the resulting average distance when shot at an angle.
- ③ Estimate the precision of the predicted range. How many of the final 10 shots landed within this range?

<b><i>Notes</i></b>
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## Experiment 3: Projectile Range Versus Angle

### EQUIPMENT NEEDED

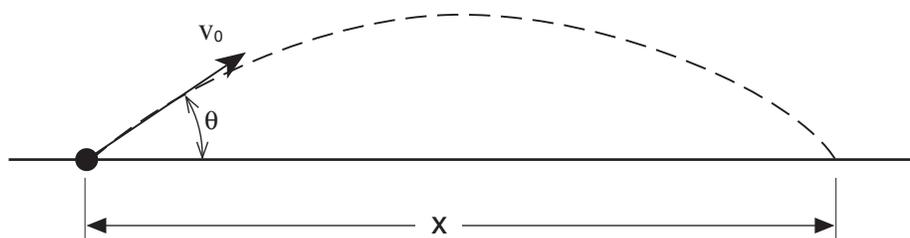
- |                                 |                |
|---------------------------------|----------------|
| – Mini Launcher and steel ball  | – Plumb bob    |
| – Measuring tape or meter stick | – Carbon paper |
| – Graph paper                   | – White paper  |

### Purpose

The purpose of this experiment is to find how the range of the ball depends on the angle at which it is launched. The angle that gives the greatest range is determined for two cases: launching on level ground and launching off a table.

### Theory

The range is the horizontal distance,  $x$ , between the muzzle of the Launcher and the place where the ball lands. The range is given by  $x = (v_0 \cos \theta)t$ , where  $v_0$  is the initial speed of the ball as it leaves the muzzle,  $\theta$  is the angle of inclination above horizontal, and  $t$  is the time of flight. See figure 3.1.



**Figure 3.1: Shooting on a level surface**

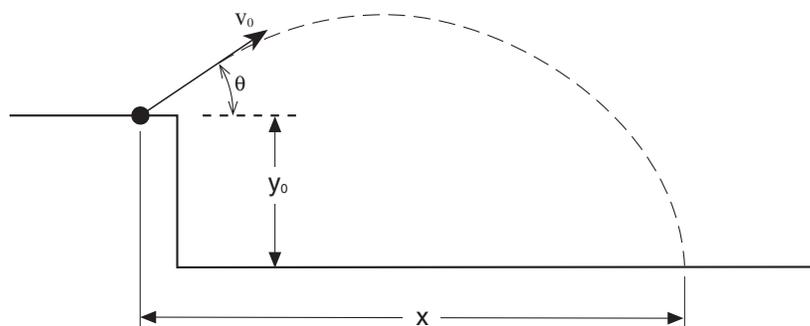
For the case in which the ball lands at the same elevation from which it was launched, the time of flight of the ball will be twice the time it takes the ball to reach the peak of its trajectory. At the peak, the vertical velocity is zero so

$$v_y = 0 = v_0 \sin \theta - gt_{peak}$$

Therefore, solving for the time gives the total time of flight as  $t = 2t_{peak} = 2 \frac{v_0 \sin \theta}{g}$ .

For the case in which the ball is launched at an angle from a table onto the floor, (See Figure 3.2) the time of flight is found using the equation for the vertical motion:

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



**Figure 3.2: Shooting off the table**

where  $y_0$  is the initial height of the ball and  $y$  is the position of the ball when it hits the floor.

### Setup

- ① Clamp the Mini Launcher near one end of a sturdy table with the Launcher aimed so the ball will land on the table. The square nut in the T-slot should be positioned near the muzzle.
- ② Adjust the angle of the Mini Launcher to ten degrees.
- ③ Put the steel ball into the Mini Launcher and cock it to the chosen position.

### Procedure

#### SHOOTING ON A LEVEL SURFACE

- ① Fire one shot to locate where the ball hits the table. At this position, tape a piece of white paper to the table. Place a piece of carbon paper (carbon-side down) on top of this paper and tape it down. When the ball hits the table, it will leave a mark on the white paper.
- ② Fire about five shots.
- ③ Measure the horizontal distance from the launch position of the ball to the leading edge of the paper. Record in Table 3.1.
- ④ Measure from the leading edge of the paper to each of the five dots and record these distances in Table 3.1.

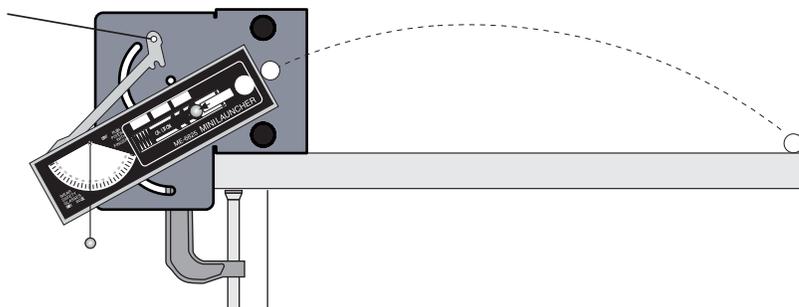


Figure 3.3: Setup to shoot on level surface

Table 3.1 Shooting on a Level Surface

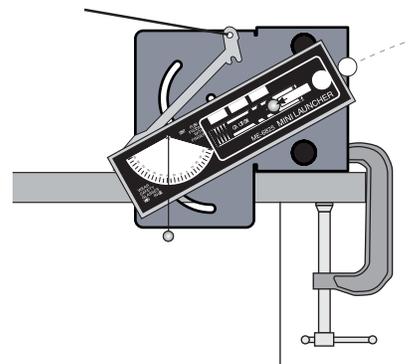
Angle	10	20	30	40	50	60	70	80
1								
2								
3								
4								
5								
Average								
Paper Dist.								
Total Dist.								

Horz. Distance

- ⑤ Increase the angle by 10 degrees and repeat all the steps.
- ⑥ Repeat for angles up to and including 80 degrees.

**SHOOTING OFF THE TABLE**

Clamp the Mini Launcher as shown in Fig 3.4 so that the ball will hit the floor. Repeat steps 1 through 6 and record the data in Table 3.2. You can use a plumb bob to find the point directly beneath the launch position of the ball.



**Figure 3.4: Setup**

**Analysis**

- ① Find the average of the five distances in each case and record in Tables 3.1 and 3.2.
- ② Add the average distance to the distance to the leading edge of the paper to find the total distance (range) in each case. Record in Tables 3.1 and 3.2.
- ③ For each data table, plot the range vs. angle and draw a smooth curve through the points.

**Table 3.2 Shooting Off the Table**

Angle	10	20	30	40	50	60	70	80
1								
2								
3								
4								
5								
Average								
Paper Dist.								
Total Dist.								

Horz. Distance

**Questions**

- ① From the graph, 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?
- ③ Is the maximum range further when the ball is shot off the table or on the level surface?

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**Notes**

## Experiment 4: Projectile Path

### EQUIPMENT NEEDED

- Mini Launcher and steel ball
- Measuring tape or meter stick
- Carbon paper
- White paper
- Movable vertical target board (Must reach from floor to muzzle)
- Graph paper

### Purpose

The purpose of this experiment is to find how the vertical distance the ball drops is related to the horizontal distance the ball travels when launched horizontally from a table.

### Theory

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

If the ball is shot horizontally, the time of flight of the ball will be

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

The vertical distance,  $y$ , that the ball falls in time  $t$  is given by

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

where  $g$  is the acceleration due to gravity.

Substituting for  $t$  into the equation for  $y$  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 near one end of a sturdy 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 the long range setting to determine the initial position of the vertical target. Place the target so the ball hits it near the bottom. See Figure 4.1.
- ④ Cover the target board with white paper. Tape carbon paper

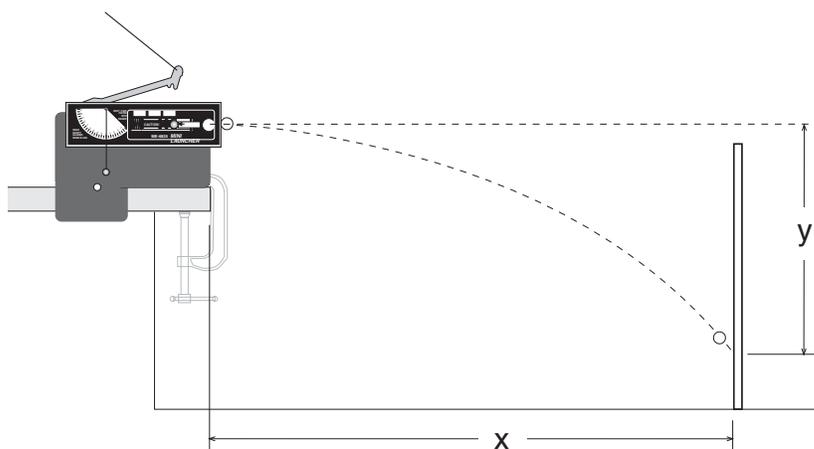


Figure 4.1: Setup

(carbon side down) over the white paper.

**Procedure**

- ① Measure the vertical height from the floor to the muzzle and record in Table 4.1. Mark this height on the target.
- ② Measure the horizontal distance from the muzzle of the Mini Launcher to the target and record in Table 4.1.
- ③ Shoot the ball.
- ④ Move the target about 5 cm closer to the Launcher.
- ⑤ Repeat Steps 2 through 4 until the ball strikes the target about 10 cm below the muzzle height.

**Table 4.1 Data**

Height of Muzzle = \_\_\_\_\_

Horizontal (x)	Height (y)	$x^2$

**Analysis**

- ① On the target, measure the vertical distances from the muzzle level mark down to the ball marks and record in Table 4.1.
- ② Calculate  $x^2$  for all the data points and record in Table 4.1.
- ③ Plot  $y$  vs.  $x^2$  and draw the best-fit straight line.
- ④ Calculate the slope of the graph and record in Table 4.2.
- ⑤ From the slope of the graph, calculate the initial speed of the ball as it leaves the muzzle and record in Table 4.2.
- ⑥ Using any data point for  $x$  and  $y$ , calculate the time using  $y$  and then calculate the initial speed using this time and  $x$ . Record the results in Table 4.2.
- ⑦ Calculate the percent difference between the initial speeds found using these two methods. Record in Table 4.2.

**Table 4.2 Initial Speed**

Slope of graph	
Initial speed from slope	
Time of flight	
Initial speed from x, y	
Percent Difference	

**Questions**

- ① Was the line straight? What does this tell you about the relationship between y and x?
- ② If you plotted y vs. x, how would the graph differ from the y vs.  $x^2$  graph?
- ③ What shape is the path of a projectile?

---

**Notes**

## Experiment 5: Conservation of Energy

### EQUIPMENT NEEDED

- Mini Launcher and steel ball
- Measuring tape or meter stick
- (optional) 2 Photogates and Photogate Bracket
- (optional) Timing System
- Plumb bob
- White paper
- Carbon paper

### Purpose

The purpose of this experiment is to show that the kinetic energy of a ball shot straight up is transformed into potential energy.

### Theory

The total mechanical energy of a ball is the sum of its potential energy (PE) and its kinetic energy (KE). In the absence of friction, total energy is conserved. When a ball is shot straight up, the initial PE is defined to be zero and the  $KE = (1/2)mv_0^2$ , where  $m$  is the mass of the ball and  $v_0$  is the muzzle speed of the ball. See Figure 5.1. When the ball reaches its maximum height,  $h$ , the final KE is zero and the  $PE = mgh$ , where  $g$  is the acceleration due to gravity. Conservation of energy gives that the initial KE is equal to the final PE.

To calculate the kinetic energy, the initial velocity must be determined. To calculate the initial velocity,  $v_0$ , for a ball shot horizontally off a table, 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. Air friction is assumed to be negligible. See Figure 5.2.

The vertical distance the ball drops in time  $t$  is given by  $y = (1/2)gt^2$ .

The initial velocity of the ball can be determined by measuring  $x$  and  $y$ . The time of flight of the ball can be found using

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

and then the initial velocity can be found using  $v_0 = x/t$ .

### Setup

- ① Clamp the Mini Launcher near one end of a sturdy table with the Launcher aimed away from the table. See Figure 5.1.
- ② Point the Launcher straight up and fire a test shot on long range. Make sure the ball does not hit the ceiling. If it does, use the medium range throughout 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.

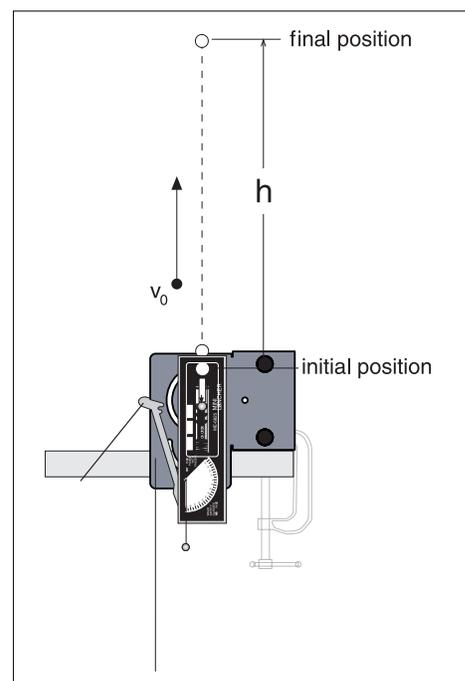


Figure 5.1: Conservation of Energy

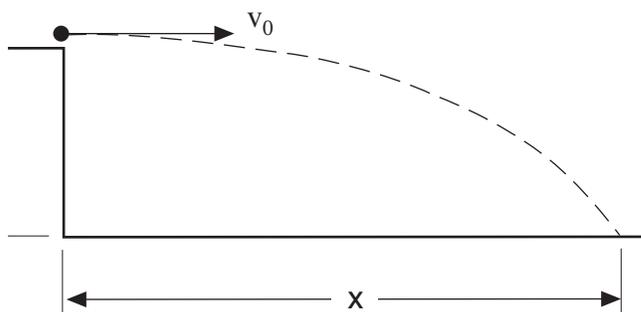


Figure 5.2: Finding the Initial Velocity

**PART I: Determining the Initial Velocity of the Ball  
(without photogates)**

- ① Put the steel ball into the Mini Launcher and cock it to the chosen range position. Fire one shot to locate where the ball hits the floor. At this position, tape a piece of white paper to the floor. Place a piece of carbon paper (carbon-side down) on top of this paper and tape it down. When the ball hits the floor, it will leave a mark on the white paper.
- ② Fire about ten shots.
- ③ Measure the vertical distance from the bottom of the ball as it leaves the barrel (this position is marked on the side of the barrel) to the floor. Record this distance in Table 5.1.
- 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 paper. Record in Table 5.1.
- ⑤ Measure from the leading edge of the 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 in Table 5.1.
- ⑦ Using the vertical distance and the average horizontal distance, calculate the time of flight and the initial velocity of the ball. Record in Table 5.1.

**Table 5.1 Determining the Initial Velocity without Photogates**

Vertical distance = \_\_\_\_\_ Calculated time of flight= \_\_\_\_\_  
 Horizontal distance to paper edge = \_\_\_\_\_ Initial velocity = \_\_\_\_\_

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

### ALTERNATE METHOD FOR DETERMINING THE INITIAL VELOCITY OF THE BALL (USING PHOTOGATES)

- ① Attach the photogate bracket to the Launcher and attach two photogates to the bracket. Plug the photogates into a computer or other timer.
- ② Adjust the angle of the Mini Launcher to 90 degrees (straight up).
- ③ Put the steel ball into the Mini Launcher and cock it to the chosen range.
- ④ Run the timing program and set it to measure the time between the ball blocking the two photogates.
- ⑤ Shoot the ball three times and take the average of these times. Record in Table 5.2.
- ⑥ The distance between the photogates is 10 cm. Calculate the initial speed of the ball and record it in Table 5.2.

**Table 5.2 Initial Speed Using Photogates**

TRIAL NUMBER	TIME
1	
2	
3	
AVERAGE TIME	
INITIAL SPEED	

### MEASURING THE HEIGHT

- ① Adjust the angle of the Launcher to 90 degrees (straight up).
- ② Shoot the ball on the chosen range setting several times and measure the maximum height attained by the ball. Record in Table 5.3.
- ③ Determine the mass of the ball and record in Table 5.3.

### Analysis

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

**Table 5.3 Results**

Maximum Height of Ball	
Mass of Ball	
Initial Kinetic Energy	
Final Potential Energy	
Percent Difference	

**Questions**

- ① How does friction affect the result for the kinetic energy?
- ② How does friction affect the result for the potential energy?

## Experiment 6: Conservation of Momentum In Two Dimensions

### EQUIPMENT NEEDED

- Mini Launcher, 2 steel balls and Collision Attachment
- Plumb bob
- Meter stick
- Protractor
- Butcher paper
- Tape to make collision inelastic
- Stand to hold ball
- Carbon paper

### Purpose

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

### Theory

A ball is shot toward another ball which is initially at rest. After the resulting collision the two balls go off in different directions. Both balls are falling under the influence of the force of gravity so momentum is not conserved in the vertical direction. However, there is no net force on the balls in the horizontal plane so momentum is conserved in horizontal plane.

Before the collision, since all the momentum is in the direction of the velocity of Ball #1, it is convenient to define the x-axis along this direction. Then the momentum before the collision is

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

and 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 net momentum in the y-direction before the collision, conservation of momentum requires that there is no momentum in the y-direction after the collision.

Therefore,

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

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 an elastic collision, 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) after the collision will be at right angles to each other.

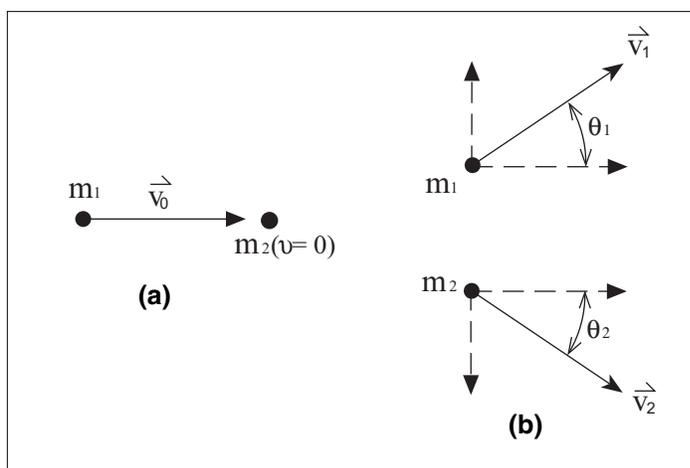


Figure 6.1: (a) Before Collision (b) After Collision

## Setup

- ① Clamp the Mini Launcher near one end of a sturdy table with the Launcher aimed inward toward the table. Mount the launcher in the top hole of the bracket.
- ② Adjust the angle of the Mini Launcher to zero degrees so the ball will be shot off horizontally onto the table. Fire a test shot to determine the range.
- ③ Place a piece of butcher paper on the table. The paper must extend to the base of the Launcher.
- ④ Mount the Collision Attachment on the Launcher. See Figure 6.2. Slide the attachment back along the Launcher until the tee is about 3 cm in front of the muzzle.
- ⑤ Rotate the attachment to position the ball from side to side. The tee must be located so that neither ball rebounds into the Launcher and so both balls land on the table. Tighten the screw to secure the collision attachment to the Launcher.
- ⑥ Adjust the height of the tee so that the two balls are at the same level. This is necessary to ensure that the time of flight is the same for each ball. Fire a test shot and listen to determine if the two balls hit the table at the same time.
- ⑦ Place a piece of carbon paper at each of the three sites where the balls will land.

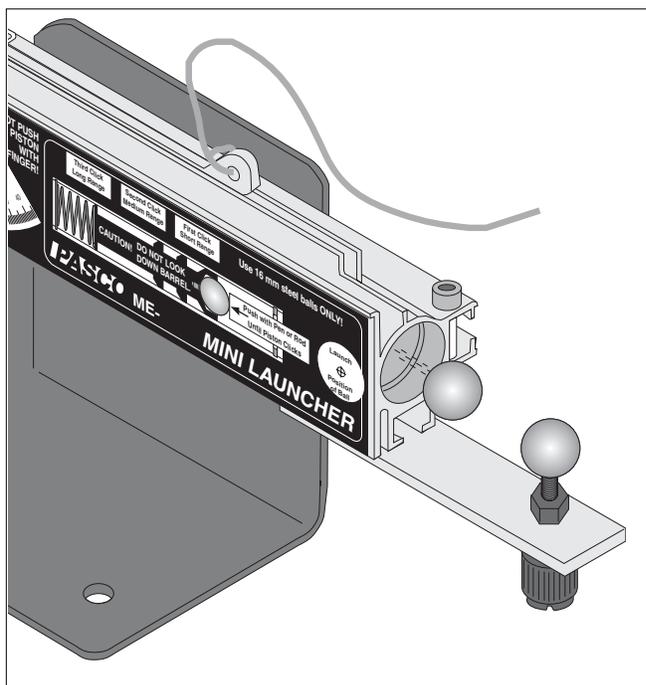


Figure 6.2: Collision Accessory Tee

## Procedure

- ① Using one ball, shoot the ball straight five times.
- ② Elastic collision: Using two balls, load one ball and put the other ball on the tee. Shoot the ball five times.
- ③ Inelastic collision: Using two balls, load one ball and stick a very small loop of tape onto the tee ball. Orient the tape side of the tee ball so it will be struck by the launched ball, causing an inelastic collision. Shoot the ball once and if the balls 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.
- ④ Use a plumb bob to locate on the paper the spot below the point of contact of the two balls. Mark this spot.

## Analysis

- ① Draw lines from the point-of-contact spot to the centers of the groups of dots. There will be five lines.
- ② Measure the lengths of all five lines and record on the paper. Since the time of flight is the same for all paths, these lengths are proportional to the corresponding horizontal velocities. Since the masses are also the same, these lengths are also proportional to the corresponding momentum of each ball.
- ③ Measure the angles from the center line to each of the outer four lines and record on the paper.

**PERFORM THE FOLLOWING THREE STEPS FOR THE ELASTIC COLLISION AND THEN REPEAT THESE THREE STEPS FOR THE INELASTIC COLLISION:**

- ④ For the x-direction, check that the momentum before equals the momentum after the collision. To do this, use the lengths for the momentums and calculate the x-components using the angles. Record the results in Tables 6.1 and 6.2.
- ⑤ For the y-direction, check that the momenta for the two balls are equal and opposite, thus canceling each other. To do this, calculate the y-components using the angles. Record the results in the Tables.
- ⑥ Calculate the total kinetic energy before and the total kinetic energy after the collision. Calculate the percent difference. Record the results in the Tables.

**Table 6.1 Results for the Elastic Collision**

Initial x-momentum		Final x-momentum		% difference	
y-momentum ball 1		y-momentum ball 2		% difference	
Initial KE		Final KE		% difference	

**Table 6.2 Results for the Inelastic Collision**

Initial x-momentum		Final x-momentum		% difference	
y-momentum ball 1		y-momentum ball 2		% difference	
Initial KE		Final KE		% difference	

**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 energy conserved for the elastic collision?
- ④ Was energy conserved for the inelastic collision?
- ⑤ For the elastic collision, was the angle between the paths of the balls after the collision equal to 90 degrees as expected?
- ⑥ For the inelastic collision, what was the angle between the paths of the balls after the collision? Why is it less than 90°?

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**Notes**

## Experiment 7: Varying Angle To Maximize Height on a Wall

### EQUIPMENT NEEDED

- Mini Launcher and steel ball
- Plumb bob
- Measuring tape or meter stick
- Carbon paper
- White paper
- Board to protect wall

### Purpose

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

### Theory

When the ball is launched at an angle from a fixed distance,  $x$ , from a vertical wall, it hits the wall at a height  $y$  given by:

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

where  $y_0$  is the initial height of the ball,  $v_0$  is the initial speed of the ball as it leaves the muzzle,  $\theta$  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 for the time of flight from the equation for  $x$  gives

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

Substituting for  $t$  in the equation for  $y$  gives  $y = y_0 + x \tan \theta - \frac{g x^2}{2 v_0^2 \cos^2 \theta}$

To find the angle that gives the maximum height,  $y$ , set  $dy/d\theta$  equal to zero and solve for the angle.

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

Solving for the angle gives

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

Since the second derivative is negative for  $\theta_{\max}$ , the angle is a maximum.

To find the initial velocity of the ball, the fixed distance  $x$  and the maximum height  $y_{\max}$  can be used. Solve the  $y$ -equation for  $v_0$  and plug in the values for  $y_{\max}$ ,  $\theta_{\max}$ , and  $x$ .

### Setup

- ① Clamp the Mini Launcher near one end of a sturdy table with the Launcher facing the wall at a distance of about 1 meter from the wall.
- ② Put a vertical board up to protect the wall.
- ③ Test fire the ball (on the long range setting) a few times to find approximately at which angle the ball strikes the wall at a maximum height.

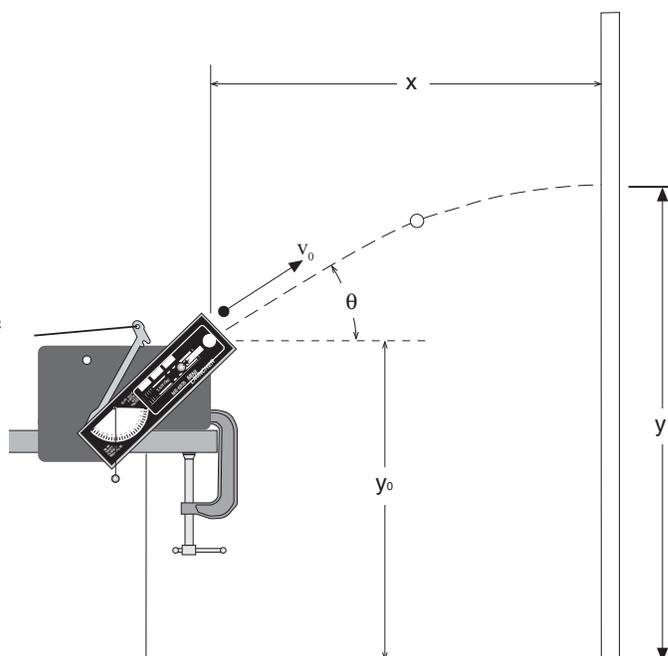


Figure 7.1: Maximizing Height

- ④ Tape a piece of white paper to the board in the region where the ball is hitting. Then cover the white paper with a piece of carbon paper.

**Procedure**

- ① Shoot the ball at various angles and pinpoint exactly which angle gives the maximum height by checking the marks on the paper.
- ② Measure the angle that produces the maximum height and record in Table 7.1.
- ③ Measure the maximum height and record in Table 7.1.
- ④ Measure the horizontal distance from the muzzle to the vertical board and record in Table 7.1.
- ⑤ Measure the initial height of the ball where it leaves the muzzle and record in Table 7.1.

**Analysis**

- ① Calculate the initial velocity by solving the y-equation for  $v_0$  and plugging in the values from Table 7.1.
- ② Calculate the angle for maximum height using the initial velocity 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 calculated angle.

**Table 7.1 Data and Results**

Measured Angle for Max	
Maximum Height	
Horizontal Distance	
Initial Height	
Calculated Initial Velocity	
Calculated Angle for Max	
% Difference Between Angles	

**Questions**

- ① For the angle at which the ball strikes the wall at the maximum height, has the ball already reached the peak of its trajectory when it strikes the wall?
- ② How far from the wall would you need to place the launcher so that when the ball is launched at  $45^\circ$  it strikes the wall at a maximum height? What would the maximum height be in this case?

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

### EQUIPMENT NEEDED

-Mini Launcher and steel ball

### Purpose

The purpose of this demonstration is to show that the range of a ball launched at 30° is the same as one launched at 60° if the ball is shot on a level surface.

### Theory

The range is the horizontal distance,  $x$ , between the muzzle of the Launcher and the place where the ball hits, given by  $x = (v_0 \cos \theta)t$  where  $v_0$  is the initial speed of the ball as it leaves the muzzle,  $\theta$  is the angle of inclination above horizontal, and  $t$  is the time of flight.

If the ball hits on a place that is at the same level 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:

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

where  $g$  is the acceleration due to gravity.

Substituting for  $t$  into the equation for  $x$  gives  $x = \frac{2v_0^2 \sin \theta \cos \theta}{g}$

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  $\sin(60^\circ) = \sin(120^\circ)$ .

### Setup

- ① Clamp the Mini Launcher near one end of a sturdy table with the Launcher aimed so the ball will land on the table. See Figure 8.1.
- ② Adjust the angle of the Mini Launcher to 30 degrees.
- ③ Put the steel ball into the Mini Launcher and cock it to the medium or long range position.

### Procedure

- ① Shoot the ball at 30 degrees to find where the ball lands.
- ② Change the angle of the Launcher to 60 degrees and shoot the ball again. Call attention to the fact that the ball again lands in the same place. Thus the ranges are the same.
- ③ Change the angle to 45 degrees and shoot the ball again to show that the ball now lands further away.
- ④ Ask the question: What other pairs of angles will have a common range? This demonstration can be done for any two angles which add up to 90 degrees: 20 and 70, or 35 and 55, etc.

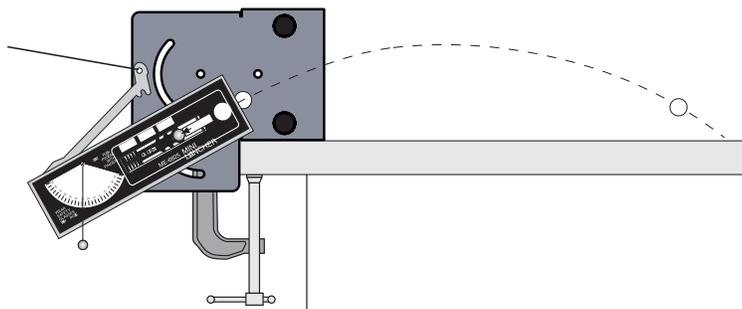


Figure 8.1: Setup to shoot on level surface

## **Experiment 9 (Demo): Simultaneously Shoot Two Balls Horizontally at Different Speeds**

### EQUIPMENT NEEDED

- 2 Mini Launchers and 2 steel balls

### Purpose

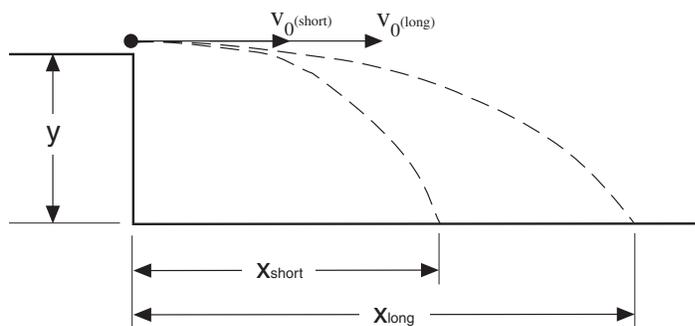
The purpose of this demonstration is to show that regardless of the initial speed of the balls launched horizontally off a table, the balls will hit the floor at the same time.

### Theory

Two balls are launched horizontally from the same table (from the same height,  $y$ ). The muzzle speeds of the two balls are different.

The vertical and horizontal motions of a projectile are independent of each other. The horizontal distance,  $x$ , travelled by the ball is dependent on the initial speed,  $v_0$ , and is given by  $x = v_0 t$ , where  $t$  is the time of flight. The time of flight depends only on the vertical distance the ball falls since

$y = (1/2)gt^2$ . Since the vertical distance is the same for each ball, the time of flight must be the same for each ball.



### Setup

- ① Clamp two Mini Launchers adjacent to each other on a sturdy table. The Launchers should both be aimed in the same direction, away from the table so the balls will land on the floor.
- ② Adjust the angle of each Mini Launcher to zero degrees so the balls will be shot horizontally off the table.

### Procedure

- ① Put a steel ball into each Mini Launcher and cock one Launcher to the short range position and cock the other Launcher to the long range position.
- ② Ask the class to be quiet and listen for the balls striking the floor. Tell them if they hear only one click, that means the balls hit the floor simultaneously.
- ③ Put both lanyards in the same hand and pull them at the same time so the balls are launched simultaneously.
- ④ After the balls hit the floor, ask the class if they heard one click or two.

## **Experiment 10 (Demo): Shooting Through Hoops**

### **EQUIPMENT NEEDED**

- Mini Launcher and steel ball
- (5) Ring clamps on stands
- (2) Photogates
- Photogate Bracket
- Meter stick
- (2) Meter stick
- (optional) Computer with Timing software

### **Purpose**

The purpose of this demonstration is to show that the path of a ball launched horizontally from a table is parabolic.

### **Theory**

The range is the horizontal distance,  $x$ , between the muzzle of the Launcher and the place where the ball hits, given by  $x = v_0 t$

where  $v_0$  is the initial speed of the ball as it leaves the muzzle and  $t$  is the time of flight.

The vertical position,  $y$ , of the ball at time  $t$  is given by  $y = y_0 - \frac{1}{2}gt^2$

where  $y_0$  is the initial height of the ball and  $g$  is the acceleration due to gravity.

### **Setup**

- ① Before the demonstration begins, find the initial velocity for the range setting to be used. Attach the photogates and use a computer to find the initial velocity or shoot the ball horizontally and measure  $x$  and  $y$  to find the initial velocity. See experiments 1 and 2.
- ② To prepare the demonstration, clamp the Mini Launcher to the table with the Launcher aimed away from the table so the ball will land on the floor.
- ③ Adjust the angle of the Launcher to zero degrees so it will shoot horizontally.

### **Procedure**

- ① In front of the class, measure the initial height of the ball at muzzle level.
- ② Calculate the horizontal and vertical positions of the ball each 1/10 second until it hits the floor.

t (sec)	$x = v_0 t$ (cm)	$y = y_0 - (1/2)gt^2$ (cm)
0.1		
0.2		
0.3		
0.4		
0.5		

- ③ Lay the 2-meter stick on the floor in a straight line away from the Launcher.
- ④ Measure off each set of  $x$  and  $y$  and place a ring clamp on a stand at each position (See Figure 10.1). If possible it is best to adjust the last two ring stands at an angle from the vertical so the ball will not have to pass through them at an oblique angle. A cup may be placed at the end of the path to catch the ball.
- ⑤ Shoot the ball through the rings.
- ⑥ Ask the class what shape of curve is formed by the rings.

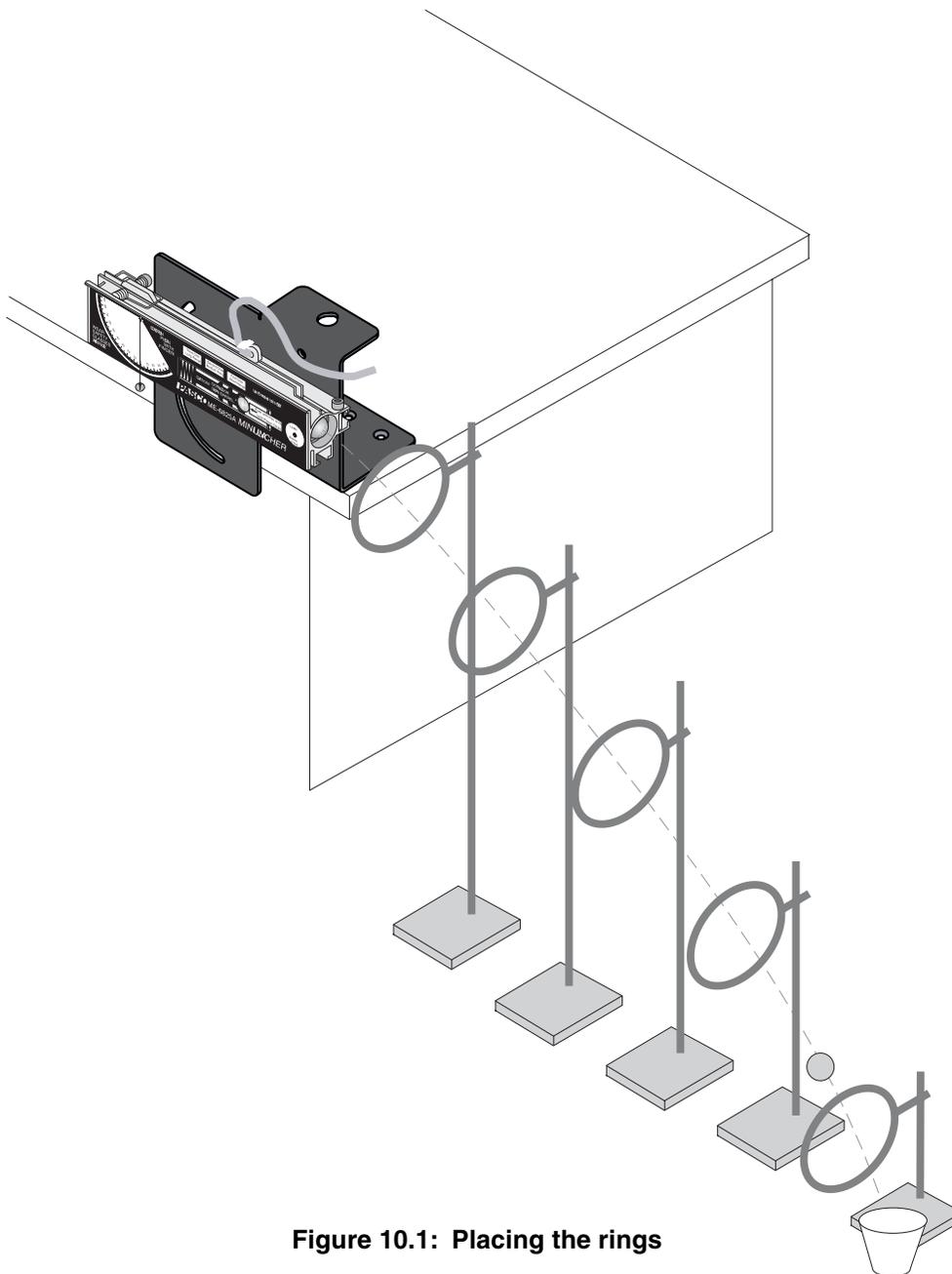


Figure 10.1: Placing the rings

# Technical Support

For assistance with any PASCO product, contact PASCO at:

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

Phone: 916-786-3800 (worldwide)  
800-772-8700 (U.S)

Fax: (916) 786-3292

Web: [www.pasco.com](http://www.pasco.com)

Email: [techsupp@pasco.com](mailto:techsupp@pasco.com)

## Limited Warranty

For a description of the product warranty, see the PASCO catalog.

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