Projectile Motion

Equipment

1	Mini Launcher	ME-6825A
2	Photogate	ME-9498A
1	Photogate Bracket	ME-6821A
1	Time of Flight	ME-6810
1	Table Clamp	ME-9472
1	Rod Base	ME-8735
1	90 cm Rod	ME-8738
1	45 cm Rod	ME-8736
1	No-Bounce Pad	SE-7347
	Required, but not included:	
	Plumb Bob	SE-8728
	Meter Stick	SE-8695
	Measuring Tape	SE-8712A
	Carbon paper	SE-8693
	850 Universal Interface	UI-5000
	PASCO Capstone Software	UI-5400

You will also need several sheets of white paper, and some type of non-marring tape, such as painter's tape.

Introduction

In this lab, students use photogates to measure time of flight and the initial launch velocity of the ball. Other activities include finding max range as a function of angle, and predicting the range fired at an angle off the table onto the floor.
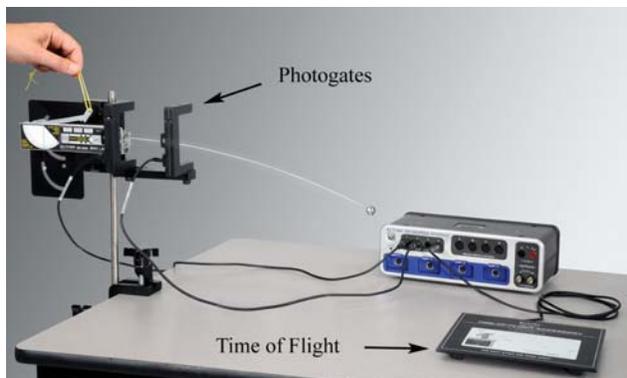
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Figure 1: Measuring the time of flight for a horizontal launch.

Setup: Table-Top Launch Height

In this section, the ball is launched from "table top" height (see Fig. 2). You will need 1.5 m to 2 m of table length.

1. The launcher is mounted on the bracket in the lower position (see Fig. 3). Slide the launcher all the way back so that it pivots about the launch position of the ball.

2. Fasten the launcher to the table using the Table Clamp. It is easier to adjust the launcher angle if you remove the knob as shown in Figure 3.

3. Use the No-Bounce Pad with Rod Base and 45 cm Rod (see Fig. 4) as a backstop to help catch the ball.

4. It is critical that you set the angle of launch (see Fig. 5) very carefully. You should be able to read/set the angle to 0.2 degrees (see Fig. 6).
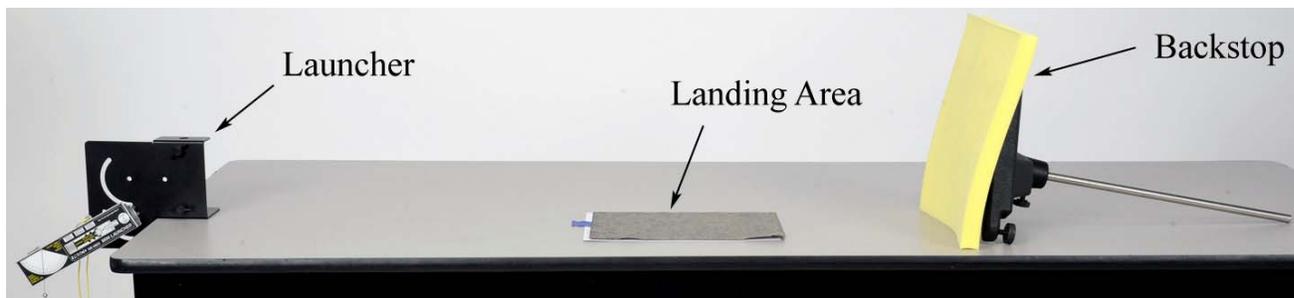

Figure 2: Launching the Ball from "Table Top" Height
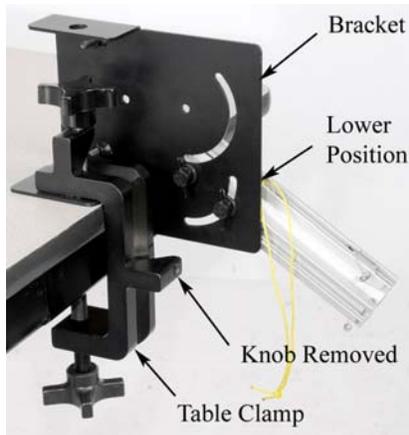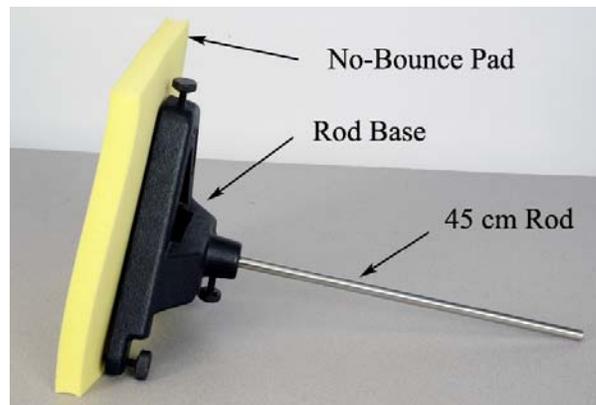
Figure 3: Launcher Mount

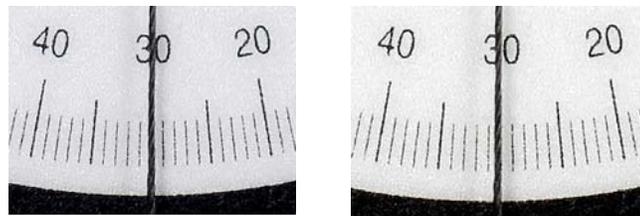Figure 4: Backstop to Catch Ball

Figure 5: Setting Launch Angle

Figure 6: The enlargement on the left shows the string centered on the 30° mark. In the figure at the far right, you can see that the string is slightly closer to 31° than 29°, and might be read as 30.2°.

Procedure:

1. Confirm that the launcher is mounted on the bracket in the lower position (see Fig. 7) so that the ball is launched from "table top" height.

2. To make your results more consistent when launching the ball, always pull on the yellow cord (attached to the trigger) with a quick short pulse. Do NOT pull slowly. Always make sure that everyone is clear before firing!

3. Set the angle for 20°. Place the ball in the piston and depress the plunger one "click" to the short range setting.

4. Launch the ball and note the landing location. Place a blank sheet of paper at this location and tape it in position as shown in Figure 8. Cover with a sheet of carbon paper. You do NOT need to tape the carbon paper.

5. Launch the ball again, and confirm that the contact point is marked. Launch the ball several more times.

6. Use a Meter Stick (see Fig. 9) to measure the ranges. This distance should be measured from the center of the launch position of the ball as shown in Figure 10. Create a table in Capstone with one column with a run-tracked user-entered data set called Distance with units of m. Turn on the statistics in the table and choose mean and standard deviation. Measure each landing point separately (see Fig. 11) and enter them into this table. Rename the run to "20 degrees".

7. Create a table in Capstone with a user-entered set of Angle with units of degrees. Enter 20, 30, 40, 50, 60, 70, and 80 in this column. In the second column, create a user-entered set called Range with units of m. Enter the average range for 20° in the table.

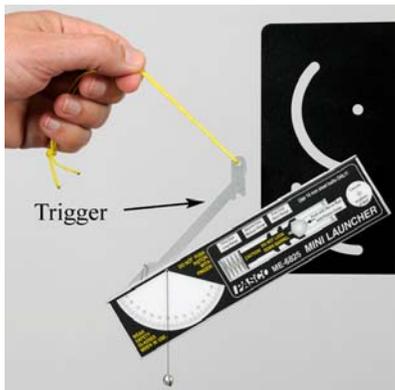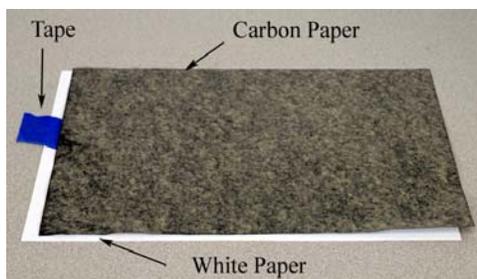Figure 7: Launching Ball   Figure 8: Landing Area
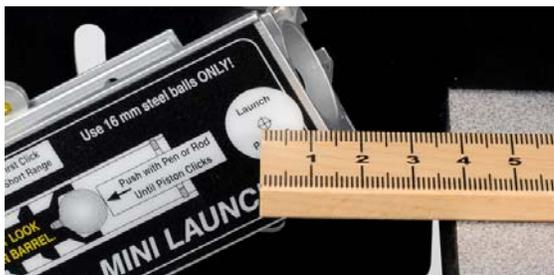
Figure 9: Measuring Range

Figure 10: Launch Position   Figure 11: Spread of Points
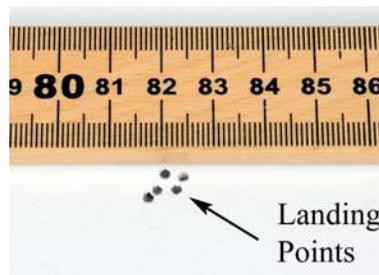
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Max Range:

8. Repeat the procedure and determine the range for angles of 30°, 40°, 50°, 60°, 70°, and 80°.

9. Create a graph of Range vs. Angle. Select a Sine Curve fit from the graph toolbar. If you have trouble with that fit, a Polynomial fit should also work.

10. In theory, the max range should occur at 45°. Does your data confirm this? Click and drag the axis to expand the scale and zoom in on the peak of the curve fit. Locate the angle for max range.

11. Is your angle less than or more than 45°? What might account for this?

12. What max range does the graph predict for your launcher? Set the launcher at that angle (from your graph) and confirm that the launcher shoots that distance.

Time of Flight Setup

In this section, the ball is launched horizontally from a height above the table, as shown in Figure 1 on the first page.

1. Fasten the launcher horizontally (see Fig. 12) on the bracket using the two screw holes, NOT the cut-out arcs.

2. Slide the launcher forward so that it projects out past the edge of the bracket as shown in Figure 13. This makes it easier to use with the Photogates attached.

3. Use the Table Clamp and 90 cm Rod to support the launcher.

4. Make sure the launch angle is exactly zero and then securely fasten all the screws.

5. Use the No-Bounce Pad with Rod Base and 45 cm Rod (see Fig. 4) as a backstop to help catch the ball.

6. Place the ball in the piston and depress the plunger all the way (three clicks) to the long range setting.

7. Launch the ball and note the landing location. If the range of the ball is too long, decrease the height of the launcher.

8. Measure the distance the ball drops: From the bottom of the ball to the top of the Time of Flight pad (see Fig. 14).

9. Plug the Time of Flight pad into Digital Input #4, and position it at the landing position of the ball.

10. Attach the Photogates to the Photogate Bracket, and slide the bracket into the T-slot on the bottom of the launcher as shown in Figure 15. You want to position the photogates to be as close to the launcher as possible. Plug the first Photogate into Digital Input #1 and the second Photogate into Digital Input #2, as shown in Figure 1.
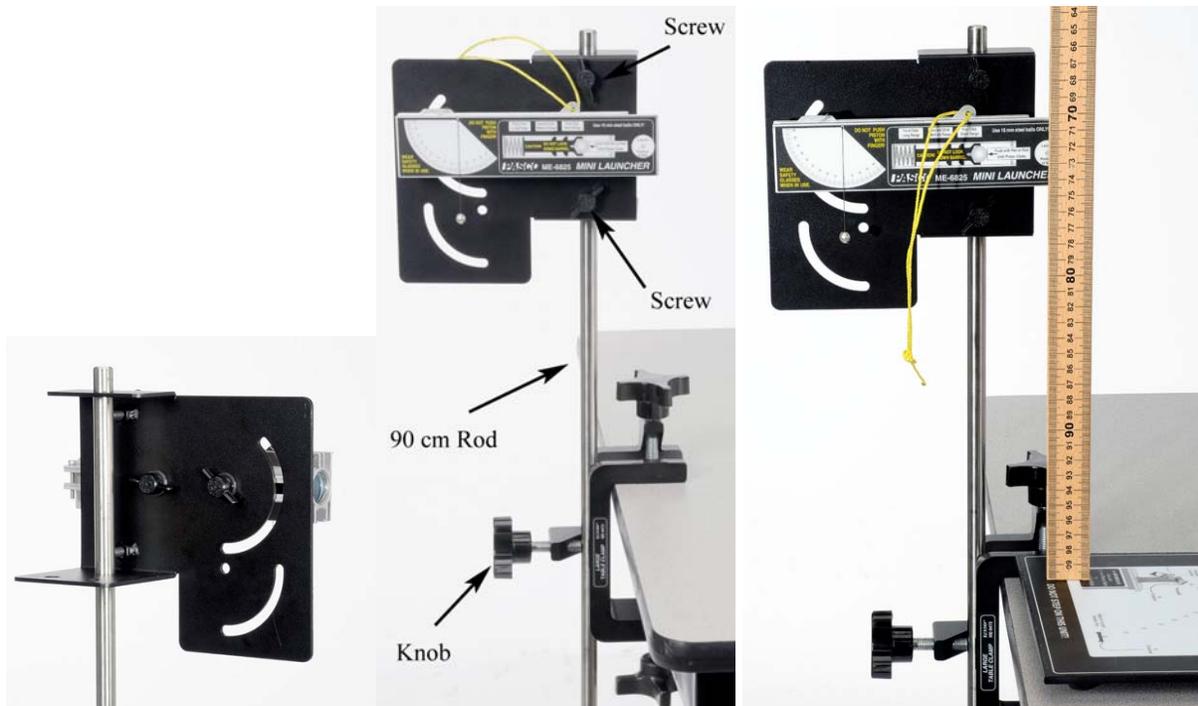

Figure 12: Launcher Mount   Figure 13: Horizontal Launch   Figure 14: Measuring Height

Figure 15: Photogates

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Procedure: 3 Ranges

1. Create two digits displays in Capstone and select the Time-of-Flight in one and Initial Speed in the other. Also create a table with three columns. In the first column, create a user-entered set called "Position" (this is the piston position) with no units and type "Long" in the first three rows, "Medium" in the next three rows, and "Short" in the next three rows. In the second column, create a user-entered set called "Speed" (this is the Initial Speed readings) in m/s. In the third column, create a user-entered set called "Time of" (this is the Time of Flight readings) in seconds.

2. Depress the plunger for long range, then click on Record. Launch the ball. The speed and time of flight should be displayed.

3. Click on Stop, and record the values in the table. Repeat for two more runs on the long range setting.

4. Repeat for the launcher set for medium range and for short range. Record three good trials for each launcher position.

5. Is the time of flight for short range less, more or **about** the same as the time of flight for medium and long range?

6. Calculate the average time of flight for all runs combined. You can use the Statistics feature in the Graph toolbar to calculate this value for you.

7. Using this average time, calculate the height, h, the ball drops

$$h = \frac{1}{2}gt^2 \hspace{2cm} (1)$$

8. Compare to the value for "h" that you measured on the previous page, using the % error calculation.

Theory: At an Angle from a Height

In this section, the ball is launched at an angle from an initial height, y_o. The initial launch velocity (v_o) is broken down into its horizontal and vertical components

$$v_{ox} = v_o cos\theta \hspace{2cm} (2)$$

$$v_{oy} = v_o sin\theta \hspace{2cm} (3)$$

where θ is the launch angle. The horizontal and vertical position of the projectile can be calculated using

$$x = v_{ox}t \hspace{2cm} (4)$$

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$$y = y_o + v_{oy}t - \frac{1}{2}gt^2 \qquad (5)$$

where a sign convention has been adopted with positive upwards.

Setup

1. Mount the launcher on the bracket in the upper position (see Fig. 16). Slide the launcher all the way back so that it pivots about the launch position of the ball.

Figure 16: Upper Position

2. Fasten the launcher to the table using the Table Clamp and 90 cm Rod as shown in Figure 17. This set-up allows you to launch the ball out onto the floor.

3. You will **not** need the Photogates if you measured the launch speeds in the previous section. You can use the No-Bounce Pad with Rod Base and 45 cm Rod (see Fig. 4) as a backstop to help catch the ball.

4. Set the angle between 20° and 60°, but not at 45°!

5. Measure the initial height, y_o, from the bottom of the ball launch position down to the floor.

6. Using a Plumb Bob, mark the launch position on a piece of tape on the floor below the launcher.

7. In the Capstone calcalator, create the following calculations:
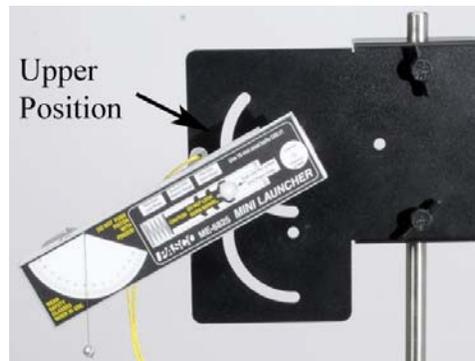
	Calculations	Units
1	height=g*t^2/2	m
2	g=9.8	m/s²
3	t=0.18	s
4	Flight Time=(vy+sqrt(vy^2+2*g*y₀))/g	s
5	y₀=0.91	m
6	vx=v₀*cos(θ)	m/s
7	v₀=[Initial Speed (m/s)]	m/s
8	θ=-20	degrees
9	vy=v₀*sin(θ)	m/s
10	Predicted Range=vx*"Flight Time"	m

8. In Capstone, create five digits displays and put in them the calculations: v_o, vx, vy, Flight

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Time, and Predicted Range

Procedure: Predicting Range

1. Decide which range (short, medium or long range) you are going to use.

2. Using the three values you measured for that range, calculate the average launch speed.

3. For the angle you set your launcher, use Eqn. (2) and Eqn. (3) to calculate the horizontal and vertical components of the initial velocity.

4. Using Eqn. (5), solve for the time of flight. Using Eqn. (4), solve for the predicted range.

5. Measure out from the launch position you marked on the floor, and tape down a piece of paper centered at your predicted range. You will try and hit this paper! Put a line on the paper showing the predicted location.

6. Your calculation was based on the average launch velocity. Using either the highest or lowest value, redo the calculations. By how much does this change your predicted range? Use this information to mark an estimated max and min on your target.

7. Cover your target with a sheet of carbon paper. Place the ball in the piston and depress the plunger to the appropriate position.

Figure 17: Launch onto Floor

8. Make sure that everyone is clear! Launch the ball and note the landing location.

9. If the ball doesn't hit the paper, find out where you made your mistake and try again! Launch a total of five balls. How many hit within your prediction?

10. Measure the distance to all five, and calculate the average. Compare this to the predicted with a % error calculation.

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