General Physics I Lab (PHYS-2011)
Experiment MECH-1:
Projectile Motion

1 EQUIPMENT

1	Mini Launcher	ME-6825
1	Time of Flight Accessory	ME-6810
1	Phone Jack Extender Cable	PI-8117
2	Photogate Head	ME-9498A
1	Photogate Bracket	ME-6821A
1	Large C Clamp (need one only)	SE-7285
1	Plumb Bob (need one only)	SE-8728
1	Carbon Paper	SE-8693
1	Metric Measuring Tape	SE-8712A
1	850 Universal Interface	UI-5000
1	PASCO Capstone	

2 INTRODUCTION

The purpose of this experiment is to predict the horizontal range of a projectile shot from various heights and angles. In addition, students will compare the time of flight for projectiles shot horizontally at different muzzle velocities. This lab experiment specifically deals with the independence of horizontal and vertical motion.

2.1 Uncertainty

The launchers work extremely well and with a combination of luck and skill you may see an accuracy of a centimeter or so over a 3-meter distance. However, small variations in cocking the launcher may cause the pattern to shift by several centimeters. We use three shot patterns and average and the results should generally be accurate to within 3 centimeters.

3 THEORY

The horizontal range, Δx, for a projectile can be found using the following equation:

$$\Delta x = v_x\, t \qquad\qquad\qquad (1)$$

where v_x is the horizontal velocity (= the initial horizontal velocity) and t is the time of flight.

To find the time of flight, t, the following kinematic equation is needed:

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$$\Delta y = \tfrac{1}{2}\, a_y\, t^2 + v_{y0}\, t \qquad\qquad (2)$$

where Δy is the height, $a_y = -g$ is the acceleration due to gravity and v_{y0} is the vertical component of the initial velocity.

When a projectile is fired horizontally (from a height Δy), the time of flight can be found by rearranging Equation 2. Since the initial vertical velocity is zero, the last term drops out of the equation yielding:

$$t = (2\, \Delta y\, /\, a_y)^{1/2} = (-2\, \Delta y\, /\, g)^{1/2} \qquad\qquad (2a)$$

When a projectile is fired at an angle and it lands at the same elevation from which it was launched, $\Delta y = 0$, and we may solve Equation (2) for t:

$$t = 2\, v_{yo}\, /\, g \qquad\qquad (2b)$$

Substituting this into Equation (1) yields

$$\Delta x = 2\, v_x\, v_{yo}\, /\, g = (2\, v^2 \cos\theta\, \sin\theta)\, /\, g \qquad\qquad (3)$$

where v is the initial speed of the projectile.

When a projectile is fired from a height, none of the terms drop out and Equation 2 may be rearranged as follows:

$$\tfrac{1}{2}\, a_y\, t^2 + v_{yo}\, t - \Delta y = 0 \qquad\qquad (2c)$$

Equation 2c may be solved using the quadratic formula to find the time of flight, t. Equation 1 then yields the horizontal range.

4   SETUP: Muzzle Velocity, Time of Flight, and Range

Safety
Wear Safety Goggles.
Do not place foreign objects into the Launcher.
Do not look into the Launcher.
Do not aim the Launcher at others.

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1.   Slide the Photogate Bracket into the groove on the bottom of the launcher and tighten the thumbscrew.

2.   Connect two photogates to the bracket (see photos below). Adjust the Photogate Bracket so

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the first photogate is as close to the launcher as possible without blocking the IR beam.

3. Attach the launcher to the launcher stand using the upper holes (see photo below).

4. Plug the photogate closest to the launcher into Digital Input 1 on the 850 Universal Interface. Plug the other photogate into Digital Input 2.

5. Plug the Time of Flight Accessory into Digital Input 3.

6. In PASCO Capstone, click on Digital Input 1 in the Hardware Setup and select a photogate. Then click on Digital Input 2 and select another photogate. Then click on Digital Input 3 and select a Time-of-Flight Accessory.

7. Open the Timer Setup and select a pre-configured timer for Time-of-Flight with Two Photogates as shown on the next page:

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The selected timer is set up as shown below:

1. Choose whether you would like to create a pre-configured timer or build your own:

   Pre-Configured Timer

2. The selected timer uses the following timing devices:

   ☑ ⌐ Photogate 1
   ☑ ⌐ Photogate 2
   ☑ ⸫ Time Of Flight Pad 3

3. The type of the selected Timer is:

   Time Of Flight (2 gates)

4. Select the measurements that will be visible (this can also be done in the Data Summary Tool):

   ☑ Initial Speed Ch 012
   ☑ Time Of Flight Ch 012
   ☐ Time Between Gates Ch 012
   ☐ Block Event Times Ch 012

5. Configure the parameters of this timer:

   Photogate Spacing 0.1   m

6. Specify the timer's name:

   Time Of Flight (2 gates)

8. Choose one corner of a table to place the projectile launcher. Make sure a distance of about 3 meters is clear on the floor in the direction the ball will be fired.

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9. Clamp the launcher to the corner of the table using a C-clamp (see photo below).

10. Using the attached plumb bob, adjust the angle of the launcher to 0º.
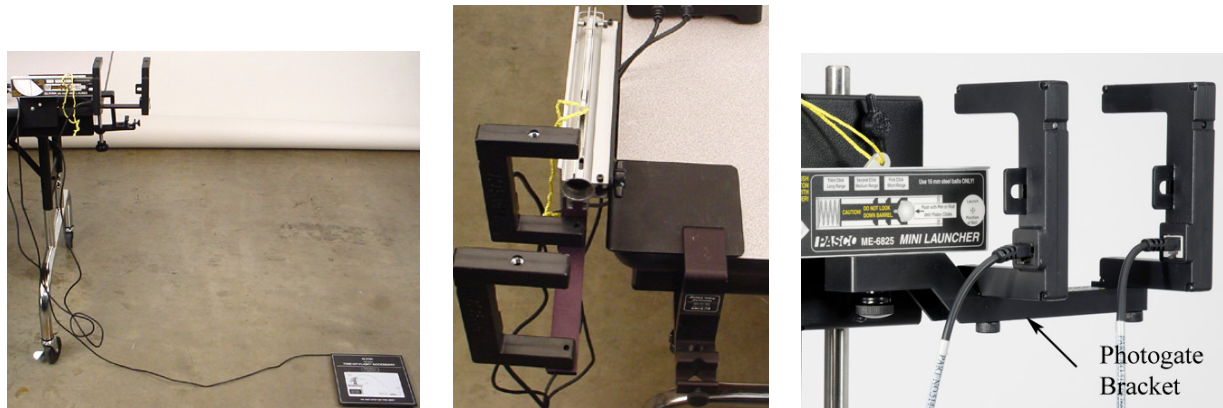
Shooting Horizontally onto the Floor

4.1 Note: Measuring angles

It is critical that you measure the angle carefully. An error of ½ degree will affect your results by several centimeters. You should be able to read the angles within 0.2 degrees. In Figure 4, the angle is 30.0°. Does Figure 5 show 30.0°? No! Notice that the line is not symmetric between the 29° and 31° marks. This angle should be read as 29.8°. In Procedure 1, it is critical that the angle be exactly 0.0°. In Procedures 2 & 3, it is not critical to exactly set the requested angle as long as you know what the exact angle is. For example, having 20.7° instead of 20.0° is fine as long as you know it is 20.7° and adjust the numbers in the table to reflect your actual angles.
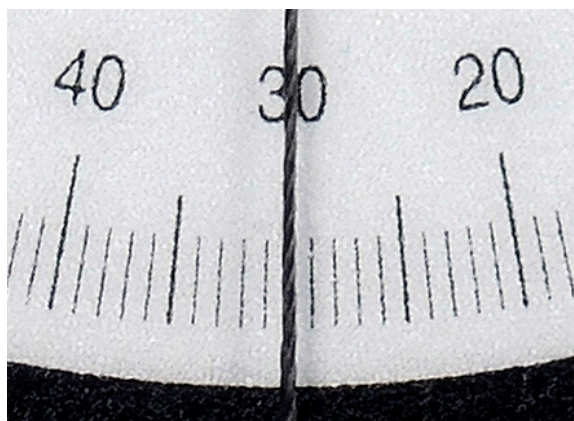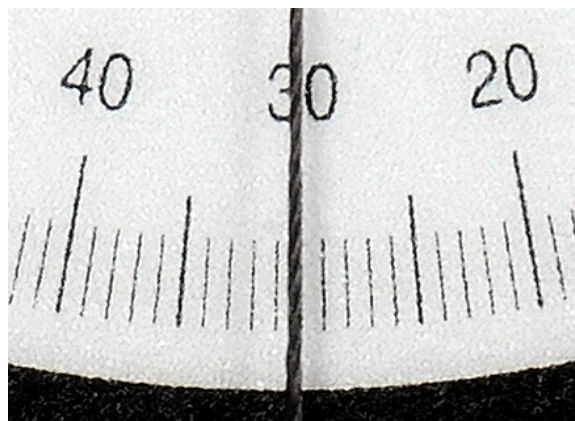

Figure 1   Figure 2

5 PROCEDURE: Muzzle Velocity, Time of Flight, and Range

Note the circle on the side of the launcher that says "Launch Position of Ball." This indicates the position of the ball when it leaves the spring and becomes a free projectile. From where on the circle should you measure the drop distance Δy? Hint: what part of the ball strikes the floor? Is Δy positive or negative? From what part of the circle should you measure Δx? In addition, measure the spacing between the two photogates and verify that it is 10.0 cm. The program calculates the initial speed by assuming the photogates are separated by 10.0 cm and dividing by the time the ball takes to travel between the two gates.

1. Measure the drop distance, Δy, to the top of the Time of Flight Accessory.

2. Carefully adjust the launcher to fire horizontally. The protractor should read exactly zero degrees. You should try to set the angle within 0.2 degrees by making the string equidistant between the +1 and -1 degree hash marks on the protractor. You will not get good results if you are not careful when setting the angles. See Note 1.

3. Place the steel ball into the launcher and use the push rod to load the ball until the third "click" is heard.

4. Check to see that there is no one down range! Launch the ball by pulling straight upward on the string. Don't jerk. Observe where the ball hits the floor. Tape a small piece of tape to the floor to mark the spot. Place the Time of Flight Accessory above the piece of tape so the ball will strike it.

5. Reload the ball to the third "click" and start recording in Capstone.

6. Pull the launch cord on the launcher. Click the Stop button to stop recording.

7. Create a table to record the Initial Speed and the Time of Flight as shown below. Create User-Entered data sets called "# Clicks" with no units, "V initial" with units of m/s, and "Time-of-Flight" with units of seconds.

Table I: Time of Flight vs. Initial Speed

	# Clicks	V inital (m/s)	Time-of-Flight (s)
1	3		
2	3		
3	3		
4	2		
5	2		
6	2		
7	1		
8	1		
9	1		

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8. Repeat two more times with the launcher cocked to three clicks.

9. If the launcher is only compressed to two clicks, will the time of flight be more, less, or the same as for 3 clicks? Explain your logic.

10. Repeat steps 2-8 for 2 clicks and 1 click. Record your results in Table I. Did you answer correctly in step 9? Why or why not?

11. Using your data and Equation 1, calculate the Δx distance to where the ball should strike the floor when the launcher is compressed two clicks. Drop a plumb line from the center of the Launch Position of Ball circle and mark the position with a piece of tape. Measure a distance equal to Δx along a line between the piece of tape you just put on the floor and the one from step 4. Tape a piece of white paper to the Time of Flight apparatus and place it at your predicted impact point. Mark your predicted impact point with an X. Place a piece of carbon paper on top of the paper (face down). Launch the ball three times using the two click position. Turn in this paper as part of your lab report!

6 CONCLUSIONS

1. Did the time of flight depend on the initial horizontal speed? What does this imply about the dependence of the vertical motion on the horizontal motion?

2. Use Equation 2a from the theory to calculate the time of flight.

3. How well does the time of flight calculated from Equation 2a agree with your experimental values. If they don't agree, what could explain the difference?

4. How well did your predicted range compare to the actual range? What does this show?

5. How would the horizontal range change if the muzzle velocity was doubled? Explain how you know.

6. How would the horizontal range change if the height from the ground was doubled? Explain how you know.

7. How would the horizontal range change if the mass of the ball was doubled? Explain how you know.

8. What effect are we able to ignore in this experiment? Explain.

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