Experiment: Projectile Motion

OBJECTIVES

1. Measure the velocity of a ball using two Photogates for timing.
2. Apply concepts from 2-D kinematics to predict the impact point of a ball in projectile motion.
3. Take into account trial-to-trial variations in the velocity measurements when calculating the impact point.

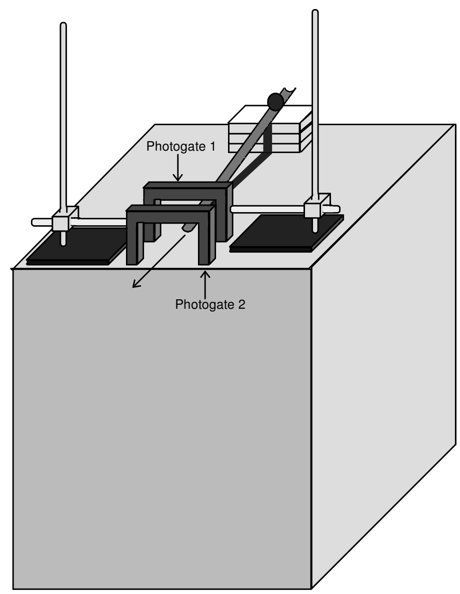

Figure 1

INTRODUCTION

You have probably watched a ball roll off a table and strike the floor. What determines where it will land? Could you predict where it will land? In this experiment, you will roll a ball down a ramp and determine the ball's velocity with a pair of Photogates. You will use this information and your knowledge of physics to predict where the ball will land when it hits the floor.

MATERIALS

- Windows-based PC
- two Vernier Photogates
- LabLab Interface
- Logger*Pro* software
- ball (1 to 5 cm diameter)
- masking tape
- plumb bob
- ramp
- two ring stands
- two right-angle clamps
- meter stick or metric measuring tape
- target

PRELIMINARY QUESTIONS

1. If you were to drop a ball, releasing it from rest, what information would be needed to predict how much time it would take for the ball to hit the floor? What assumptions must you make?

2. If the ball in Question 1 is traveling at a known horizontal velocity when it starts to fall, explain how you would calculate how far it will travel before it hits the ground.

3. A pair of computer-interfaced Photogates can be used to accurately measure the time interval for an object to break the beam of one Photogate and then another. If you wanted to know the velocity of the object, what additional information would you need?

PROCEDURE

1. Set up a low ramp made of angle molding on a table so that a ball can roll down the ramp, across a short section of table, and off the table edge as shown in Figure 1.
2. Position the Photogates so the ball rolls through them while rolling on the horizontal table surface (but *not* on the ramp). Center the detection line of each Photogate on the middle of the ball. Connect Photogate 1 to the DIG/SONIC 1 Port of the LabPro interface and Photogate 2 to DIG/SONIC 2. To prevent accidental movement of the Photogates, use tape to secure the ringstands in place.
3. Mark a starting position on the ramp so that you can repeatedly roll the ball from the same place. Roll the ball down the ramp through each Photogate and off the table. Catch the ball as soon as it leaves the table. ***Note**: Do not let the ball hit the floor during these trials or during the following velocity measurements.*
4. Prepare the computer for data collection by opening the Logger*Pro* experiment file: "08 Projectile Motion".
5. Carefully measure the distance from the beam of Photogate 1 to the beam of Photogate 2. (It may be easier to measure from the leading edge of Photogate 1 to the leading edge of Photogate 2.) To successfully predict the impact point, you *must* obtain an accurate measurement.

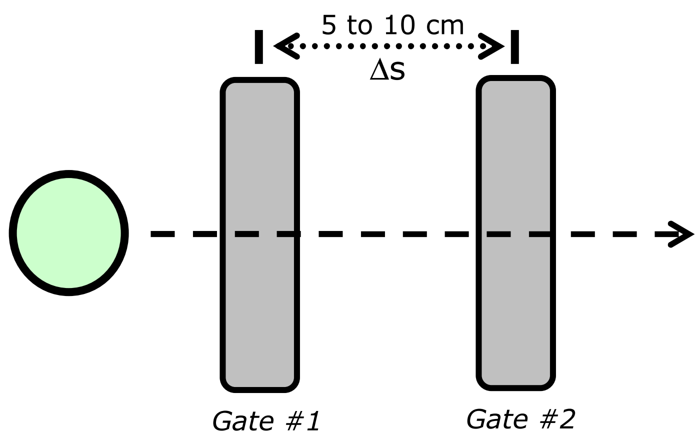

Figure 2

6. Set the "Gate Spacing" value to the measured distance between Photogates, Δs, using the arrow buttons. The program will divide this distance by the measured time interval Δt to calculate the average velocity ($v_{avg} = \Delta s/\Delta t$).
7. Begin Data collection and verify that the Photogates are responding properly by moving your finger across each photogate. Logger *Pro* will plot a time interval (Δt) value for each instance you run your finger through Photogate 1 or Photogate 2. Stop collection then re-start to clear the trial data and prepare for data collection.
8. Roll the ball from the mark on the ramp, through both Photogates, and catch the ball immediately after it leaves the table. Repeat nine more times. If the collection time runs out before all of your measurements are made, set the time interval to 120 s and re-collect your measurements.

   Take care not to bump any of the Photogates after you begin data collection or your velocity data will not be very precise. After the last trial, stop collection. Record the velocity for each trial in the data table.
9. Inspect your velocity data. Did you get the same value every time? Use the Statistics feature to determine the average, maximum, and minimum values. What one value would be most representative of all ten measurements?
10. Carefully measure the distance from the table top to the floor and record it as the table height h in the data table. Use a plumb bob to locate the point on the floor just

beneath the point where the ball will leave the table. *Mark this point with tape; it will serve as your floor origin.*

11. Use your velocity value to calculate the distance from the floor origin to the impact point where the ball will hit the floor. You will need to algebraically combine following kinematic relationships for motion with constant acceleration:

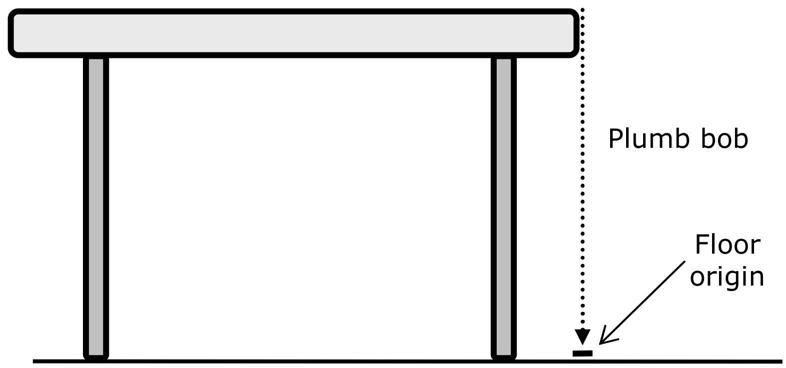

Figure 3

$$\Delta x = v_{ox}t + \tfrac{1}{2}a_x t^2$$
$$\Delta y = v_{oy}t + \tfrac{1}{2}a_y t^2$$

where $t_o=0$ and $\Delta t = t = t_{fall}$.

11. Simplify the equations above by removing the variables that equal 0.

12. Consider the following questions:
   a. *What is the value of the initial velocity in the vertical direction (v_{oy})?*
   b. *What is the acceleration in the horizontal direction (a_x)?*
   c. *What is the acceleration in the vertical direction (a_y)? Remember that the time the ball takes to fall is the same as the time the ball flies horizontally.*

   Use this information and the simplified equations to calculate how far the ball should travel horizontally during the fall. Record prediction in the Data table.

13. Mark your predicted impact point on the floor with tape and position a target at the predicted impact point. Be sure the impact point is along the line of the track.
14. Estimate the range of uncertainty in your prediction in step 13 by repeating the calculations using the minimum and maximum velocity values, respectively. These two additional calculations estimate the limits of impact range, considering the variation in your velocity measurements. *Mark these points on the floor as well.*
15. After your instructor gives you permission (*instructor's power trip…*☺), release the ball from the marked starting point, and let the ball roll off the table and onto the floor. Mark the point of impact with tape. Measure the distance from the floor origin to the actual impact and enter the measurement in the data table.

DATA TABLE

Trial	Velocity (m/s)			
1				
2				
3		**Maximum velocity**		m/s
4		**Minimum velocity**		m/s
5		**Average velocity**		m/s
6		**Table height**		m
7		**Predicted impact point**		m
8		**Minimum impact point**		m
9		**Maximum impact point**		m
10		**Actual impact point distance**		m

ANALYSIS

1. Should you expect any numerical prediction based on experimental measurements to be exact? Why would a *range* for the prediction be more appropriate? Explain.

2. Was your actual impact point between your minimum and maximum impact predictions? If so, your prediction was successful.

3. You accounted for variations in the velocity measurement in your range prediction. Are there other measurements you used which affect the range prediction? What are they?

4. Did you account for air resistance in your prediction? If so, how? If not, how would air resistance change the distance the ball flies?

5. Derive one equation for the horizontal displacement of the ball's motion in this experiment, using only initial velocity and vertical displacement.