Projectile Motion (Photogate)

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.

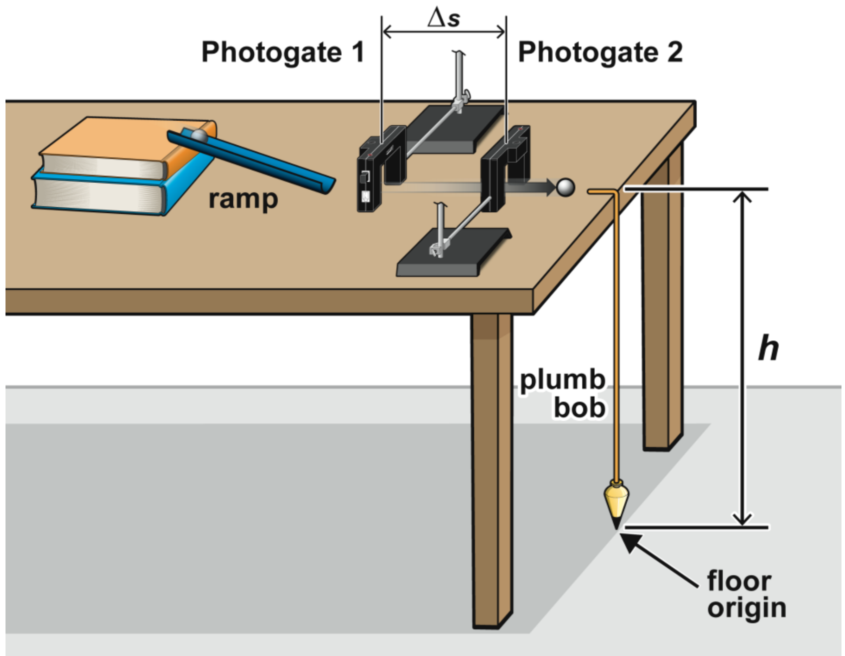

Figure 1

OBJECTIVES

- Measure the velocity of a ball using two Photogates.
- Apply concepts from two-dimensional kinematics to predict the impact point of a ball in projectile motion.
- Take into account trial-to-trial variations in the velocity measurement when calculating the impact point.

MATERIALS

LabQuest
LabQuest App
2 Vernier Photogates
ball (1 to 5 cm diameter)
masking tape
plumb bob
ramp and books
2 ring stands
2 right-angle clamps
meter stick **or** metric measuring tape
target

PRELIMINARY QUESTIONS

Balance one penny on the edge of a table. Place your index finger on a second penny, then flick the second penny so that it travels off the table, while the first penny is gently nudged off the edge. It may take a few practice trials to be able to do this effectively.

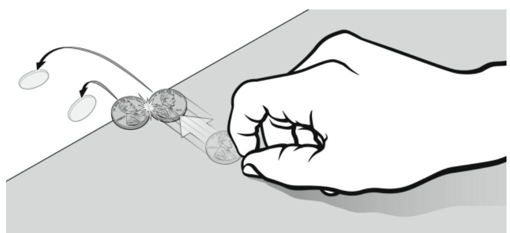

Figure 2

1. Predict which penny will land first, the penny moving horizontally, or the one that simply drops off the table. Explain.
2. Perform the investigation, listening for the sound of the pennies as they land. Was your prediction supported or refuted?
3. You may believe the pennies landed just a little bit apart from each other. Try it a few more times. Does one always land before the other?
4. What will happen if you increase the speed of the second penny? Predict and then give it a try.
5. What if you increase the height from which the pennies are dropped? Your instructor may choose to stack two tables for you to test this.
6. Based on your observations, does the horizontal speed of the flicked penny affect the impact times of the pennies?
7. What can you then say about the time to hit the floor for each penny?

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 each of the Photogates while rolling on the horizontal table surface (but *not* on the ramp). The Photogates should be 8 to 10 cm apart. To prevent accidental movement of the Photogates, use tape to secure the ring stands 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 so as not to spoil the prediction. The ball must not strike the side of the Photogates. Move the Photogates if necessary.

4. Set up the Photogates and LabQuest to collect data in Pulse Timing mode.
   a. Connect the Photogates to LabQuest and choose New from the File menu. **Note**: Connect the sensors so that the ball first passes through the Photogate connected to the digital (DIG 1) port and then passes through the Photogate connected to the digital (DIG 2) port.
   b. On the Meter screen, tap Mode. Change the Photogate Mode to Pulse Timing.
   c. You must adjust the distance between Photogates in order for LabQuest to calculate the velocity correctly for successfully predicting the impact point. The program will divide this distance by the time interval Δt it measures to get the velocity ($v = \Delta s/\Delta t$). Carefully measure the distance from the beam of Photogate 1 to the beam of Photogate 2. You can use the seam on each Photogate body as your guide, as the seam is centered at the detector. Enter the distance between gates (in meters).

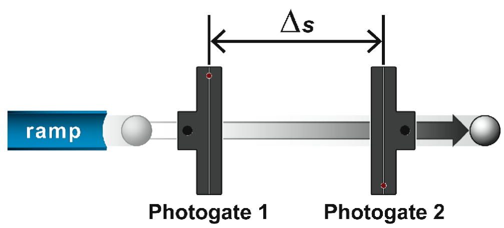

Figure 3

   d. Select OK.

5. Observe the live readings. Block Photogate 1 with your hand; note that the Photogate is shown as Blocked on the screen. Remove your hand and the display should change to Unblocked. Repeat for Photogate 2.

6. LabQuest measures the time interval from when the first photogate is blocked to the time at which the second photogate is blocked. You can see how this works by blocking the gates briefly with your finger.
   a. Start data collection.
   b. Check to see that the Photogates are responding properly by moving your finger through Photogate 1 and then Photogate 2. LabQuest App will plot a time interval (Δt) value for each instance you run your finger through Photogate 1 and then through Photogate 2.
   c. Stop data collection.
7. Collect data.
   a. Start data collection.
   b. Roll the ball from the mark on the ramp, through both Photogates, and catch the ball immediately after it leaves the table.
   c. Repeat nine times. Take care not to bump any of the Photogates, or your velocity data will not be accurate.
   d. After the last trial, stop data collection.
8. Tap the Table tab. Record the velocity for each trial number in the data table.
9. Inspect your velocity data. Did you get the same value every time? To determine the average, maximum, and minimum values, tap the Graph tab, then choose Statistics ►Velocity from the Analyze menu. Enter these values in Table 2.
10. Carefully measure the distance from the tabletop to the floor and record it as the table height, h, in Table 2. Use a plumb bob to locate the point on the floor just beneath the point where the ball will leave the table, as shown in Figure 1. Mark this point with tape; it will serve as your *floor origin*.
11. Use your average velocity value to calculate the distance from the floor origin to the impact point where the ball will hit the floor. Record the value in Table 2 as the predicted impact point.

    Align your predicted impact point with the track and mark the predicted impact point on the floor with tape. Position a target at the predicted impact point.
12. To account for the variations you saw in the Photogate velocity measurements, repeat the calculation in the preceding step for the minimum and maximum velocity. These two additional points show the limits of impact range that you might expect, considering the variation in your velocity measurement. Mark these points on the floor as well, and record the values in Table 2.
13. After your instructor gives you permission, 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 distance in the data table.

DATA TABLE

Table 1	
Trial	Velocity (m/s)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Table 2	
Maximum velocity	m/s
Minimum velocity	m/s
Average velocity	m/s
Table height	m
Predicted impact point	m
Minimum impact point distance	m
Maximum impact point distance	m
Actual impact point distance	m

ANALYSIS

1. Why is it more appropriate to use an impact range to predict the landing point of the ball? Should you expect any numerical prediction based on experimental measurements to be exact? Explain.

2. Was your prediction acceptable? Explain.

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?

EXTENSIONS

1. Derive one equation for the horizontal and vertical coordinates of the ball's motion in this experiment.
2. Repeat the experiment using a table that is not horizontal.
3. Derive a general formula for projectile motion with the object launched at an angle.
4. Calibrate the velocity of the ball when released from various positions along the ramp. Given a specific distance to the target by the instructor, determine where the ball must be released to achieve the needed velocity. Release the ball from that position and determine whether the target is hit.