Physics I – Lab #3 Projectile Motion

Part 1: Video Physics

DATA ACQUISITION

You will be shooting your own movie of a simple parabolic projectile flight and analyzing the movie within Logger Pro (see Figure 1). You will need some sort of device capable of shooting video (smartphones work fine; there are some tablets, portable video cameras, and GoPro cameras available for your use if you don't have a smartphone).

Keep the following tips in mind when you shoot your movie:

1. It is best to have a plain background that provides sufficient contrast with the projectile. Good lighting is essential.
2. Set up the camera so that it is looking square at the background, and so that the plane of motion is perpendicular to the view.
3. Position the camera as far from the plane of motion as is practical to reduce problems with scaling and parallax. Move your camera a distance far enough away to fill the screen with the motion.
4. The object used for scaling (e.g. a meter stick) must be in the same plane as the motion of the projectile (see Figure 1).
5. Try to make sure that your recording field of view has the full path of the ball's flight, but not much more. The perfect video has a field of view like the one shown in the figure below. Also, it will make things easier if the video you shoot doesn't have much recording time before or after the ball is tossed.
6. Make sure that you are using a *linear* (not fish-eye) camera to record your motion. On iPhones, this is the camera that you use for 1x zoom or larger. Smaller zooms (e.g 0.5x) use a fisheye camera lens and should **not** be used for this experiment.

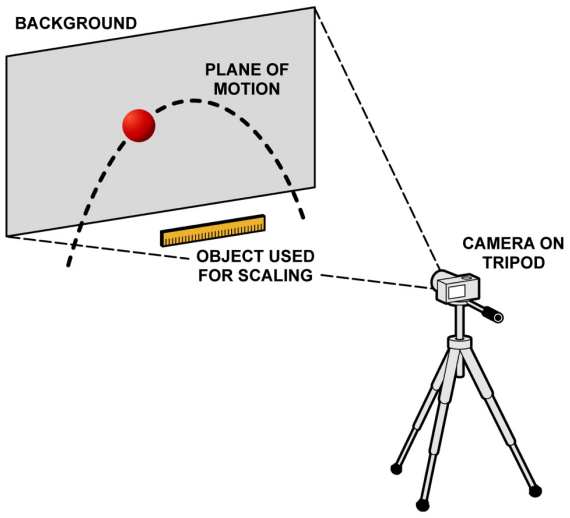


Figure 1

Once you have shot your movie, transfer the video clip to the computer you will use for the analysis by emailing it yourself or pulling out the memory card and putting it in a card reader. If you have captured a lot more video than you need and your movie is much too large, you may want to trim it before you transfer it to the computer.

DATA ANALYSIS

1. Start Logger *Pro*. Choose Movie from the Insert menu. Find and insert the movie you shot.

2. Make the movie window large enough to easily see the projectile.

3. Enable Video Analysis by clicking on the button in the lower-right corner. This brings up a toolbar with a number of buttons (see Figure 2).

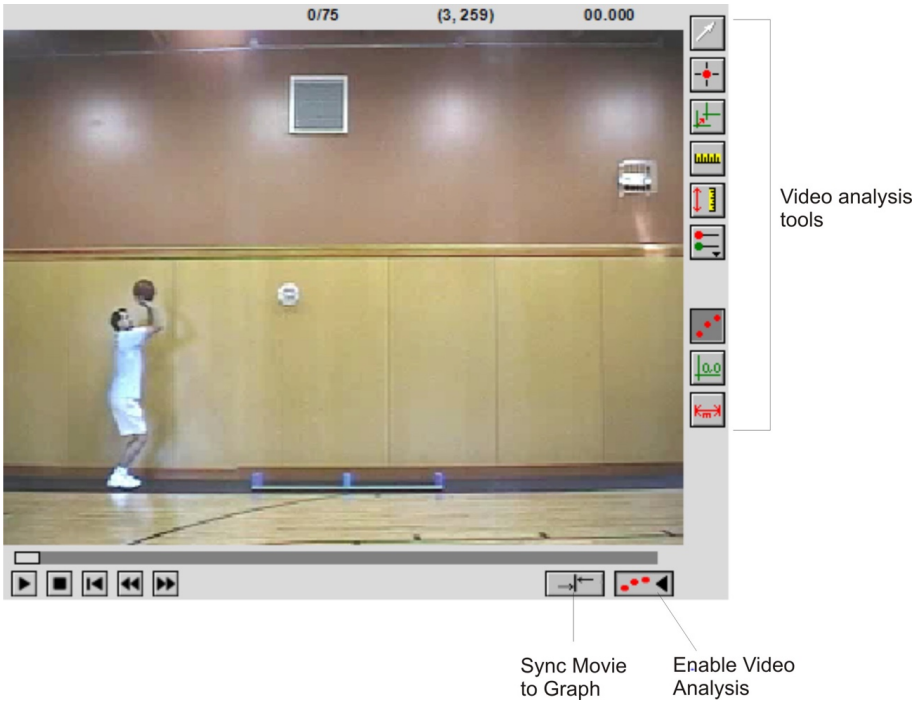


Figure 2



3. Use the forward and back movie buttons to advance the movie to the moment the ball is released from your hand.



4. Click the **Set Origin** button (third from top), then click in the movie frame to set the location of the origin. If needed, this coordinate system can be rotated by dragging the yellow dot on the horizontal axis.



5. Click the **Set Scale** button (fourth from top), then drag across an object of known length in the movie. When you release the mouse button, enter the length of the object; be sure the units are correct.



6. Use the forward and back movie buttons to advance the movie until the ball is released from the shooter's hands. Next to the button you used to enable analysis is the **Sync Movie to Graph** button. Click this button, then enter **0** in the graph time window. Select Use This Synchronization in Video Capture.



7. Now click the **Add Point** button (second from the top). Decide where on the object you will mark its location (center, top, other) and then click the object in the movie. **Important**: Be consistent in your marking.

   Each time you mark the object's location, the movie advances one frame. Notice that data are being plotted on the graph.



8. Continue this process as long as is desired. Should you wish to edit a point, click the **Select Point** button (top). This allows you to move or delete a mismarked point.

9. Select the graph window. Logger *Pro* defaults to display both the *x* and *y* positions of the object as a function of time. You may find it easier to examine the position-time behavior of just one of these components at a time.

EVALUATION OF DATA

1. Examine the graph of *x*-position *vs.* time. If it appears to be linear, fit a straight line to your data. If the slope of the graph appears to change abruptly, fit separate straight lines to each portion of the graph that appears to be linear (by selecting a box around the points you want to fit in the graph).

2. Write the equation that describes the *x*-position *vs.* time behavior of the ball in each segment; be sure to include units.

3. Describe the horizontal component of the motion of the projectile. Note when any change in the horizontal component of the motion occurs.

4. Now, examine the graph of *y*-position *vs.* time. Fit an appropriate curve to this graph (or to each portion of the graph). Write the equation that describes the *y*-position *vs.* time behavior of the ball in the first segment; be sure to include units.

5. Describe the vertical component of the position of the projectile.

6. Now, to test your analysis in Step 5, examine the graph of *y*-velocity *vs*. time (Insert→Graph). Fit a straight line to the "free fall" portion of the graph.

7. What can you say about the *rate of change* of the *y*-velocity as a function of time? How does the value of the slope of the linear fits compare to the acceleration of a freely falling object?

8. Compare the A and B parameters (values and units) to the curve fits you performed in Step 4 to the slope and intercept of the linear fits you performed in Step 6.

9. Explain the differences in the horizontal and vertical components of the motion of the projectile in terms of the acceleration(s) acting on it after it was launched.

10. Suppose that, in the shooting of your movie, you placed the meter stick used for scaling against the wall you used for your background. However, the plane of the ball's motion was 0.50 m in front of the wall. The distance between the camera and the wall was 5.0 m. Would this error result in a value for a_g in your analysis of the *y*-velocity *vs.* time graph that was smaller or larger than the accepted value? By what factor would this value differ from the expected value? Explain, using a diagram.

Part 2: Landing Zone

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.

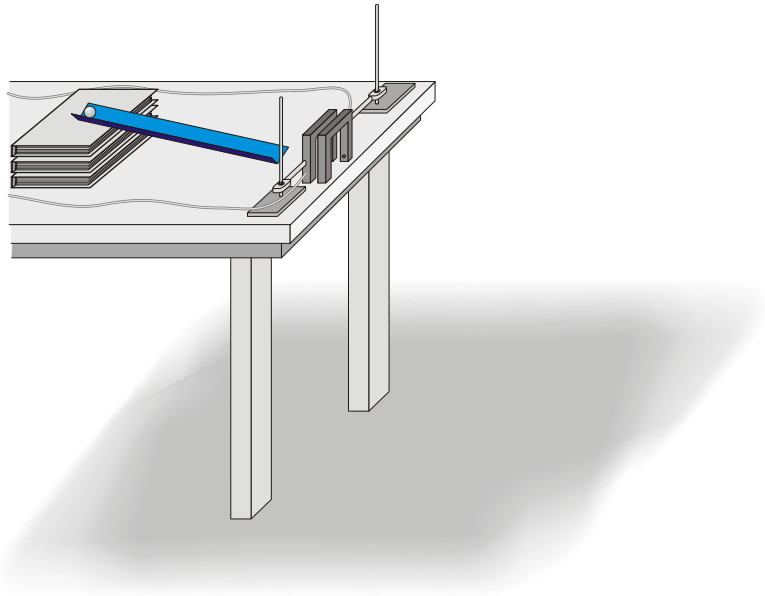


Figure 1

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 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 each of the Photogates while rolling on the horizontal table surface (but *not* on the ramp). The photogates should be on the order of 8-10 cm apart. Approximately center the detection line of each Photogate on the middle of the ball. Connect Photogate 1 to DIG/SONIC 1 of the interface and Photogate 2 to the corresponding second port. 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.** Make sure that the ball does not strike the sides of the Photogates. Reposition the Photogates if necessary.

4. Open the file "08 Projectile Motion" in the *Physics with Vernier* folder. A data table and two graphs are displayed; one graph will show the time required for the ball to pass through the Photogates for each trial and the other will display the velocity of the object for each trial.

5. You must enter the distance, Δs, between Photogates in order for Logger *Pro* to calculate the velocity. 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. (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* enter an accurate measurement. Adjust the gate separation using the control on the Logger *Pro* screen.

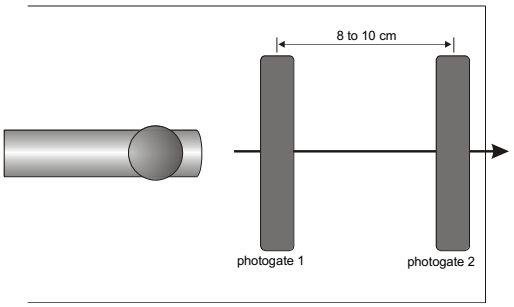


Figure 2

6. Click ▸ Collect. Check to see that the Photogates are responding properly by moving your finger through Photogate 1 and then Photogate 2. Logger *Pro* will plot a time interval (Δt) value for each instance you run your finger through Photogate 1 or Photogate 2. Click ■ Stop, then click ▸ Collect again, to clear the trial data and prepare for data collection.

7. Roll the ball from the mark on the ramp, through both Photogates, and catch the ball immediately after it leaves the table. Repeat nine times. Take care not to bump any of the Photogates, or your velocity data will not be precise. Data collection will stop after two minutes. If you need more time, click ▸ Collect to restart, choosing Append. After the last trial, click ■ Stop to end data collection. Record the velocity for each trial number in the data table.

8. Inspect your velocity data. Did you get the same value every time? Determine the average, maximum, and minimum values by clicking once on the velocity *vs*. time graph and then clicking the Statistics button, 1/2 STAT. What one value would be most representative of all ten measurements?

9. 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*.

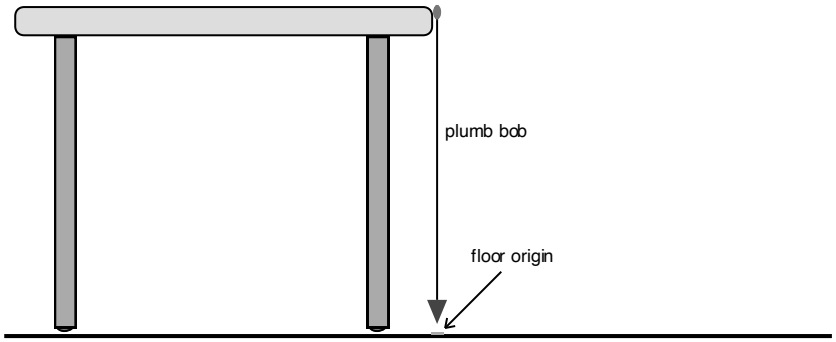


Figure 3

10. 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 relationships for motion with constant acceleration

$$\Delta x = v_{0x}t + \tfrac{1}{2}a_x t^2$$

$$\Delta y = v_{0y}t + \tfrac{1}{2}a_y t^2$$

First, simplify the equations above. What is the value of the initial velocity in the vertical direction (v_{0y})? What is the acceleration in the horizontal direction (a_x)? 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.

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.

11. To account for the variations you saw in the Photogate velocity measurements, repeat the calculation in Step 10 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.

12. After you have carefully predicted the landing zone, 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 TABLES

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

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

2. Was your actual impact point between your minimum and maximum impact predictions? If not, why not?

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? (*Think carefully about this; it may not be quite as simple as you think at first.*)

EXTRA STUFF

1. Calibrate the velocity of the ball when released from various positions along the ramp. Given a specific distance to the target, 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.

2. Increase the challenge by placing a ring on a ring stand part way to the eventual target. The ball must pass through the ring successfully and then hit the target.