

# Projectile Motion

## INTRODUCTION

Up to this point it is likely that you have examined the motion of an object in one dimension only—either on a horizontal or inclined surface, or falling vertically under the influence of Earth's gravity.

In this experiment, you will examine the behavior of a projectile—an object moving in space due to some initial launching force. Such an object can undergo motion in two dimensions simultaneously. Using the Vernier Video Analysis app, you will compare features of the position *vs.* time and velocity *vs.* time graphs with those of one-dimensional motion.

## OBJECTIVES

In this experiment, you will

- Use video analysis techniques to obtain position, velocity, and time data for a projectile.
- Analyze the position *vs.* time and velocity *vs.* time graphs for both the horizontal and vertical components of the projectile's motion.
- Determine the best fit equations for the position *vs.* time and velocity *vs.* time graphs for both the horizontal and vertical components of the projectile's motion.
- Relate the parameters in the best-fit equations for position *vs.* time and velocity *vs.* time graphs to their physical counterparts in the system.
- Relate the horizontal and vertical components of the projectile's motion to any forces acting on the object while it is moving.
- Create and analyze your own video of an object undergoing projectile motion.

## MATERIALS





Vernier Video Analysis™ app in a web browser on a computer, Chromebook, or mobile device  
tripod or other equipment to support the device  
meter stick or some other object to provide scale  
device capable of recording digital video (can be the same device running Vernier Video Analysis)  
projectile: either a ball (point particle) or an extended body  
video editing software (optional)

## PRE-LAB INVESTIGATION

Your instructor will launch a projectile. Observe its motion carefully, then discuss its position *vs.* time and velocity *vs.* time behavior.

## PROCEDURE

### Part 1 Analysis of an existing video

1. Launch Vernier Video Analysis. Scroll through the list of sample videos and choose “Basketball Shot.” Play the movie once so you can be familiar with the motion. You will analyze the video in the steps that follow.
2. Make the movie window large enough to easily see the projectile. There are two ways to do this:  
1) Click or tap the divider between the video and the other elements on the screen, and drag the divider to the right, or 2) use View, , to remove the graph and data table from view.
3. Use Step Forward, , and Step Back, , to advance the movie to the frame in which the ball is released from the shooter’s hands.
4. Set the origin and the scale in the video.
  - a. Click or tap Scale, . A set of axes and a scale bar will appear on the video.
  - b. Drag the axes to set the location of the origin. In this video, the origin is the point at which the ball leaves the person’s hands.
  - c. Drag the ends of the scale bar to the ends of an object of known length in the video. In this video, the object of known length is the meter stick on the ground.
  - d. Verify that the displayed length and units are correct based on the object of known length (i.e., 1 m).

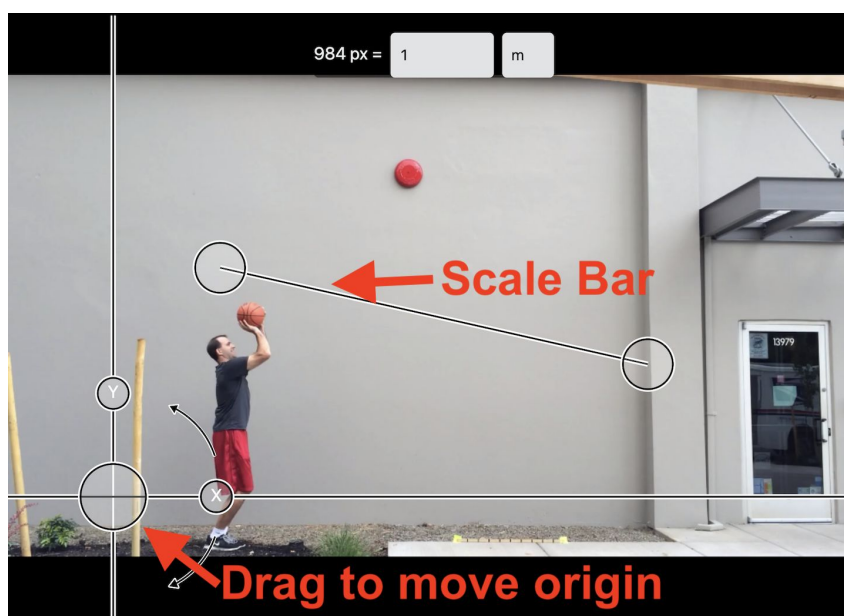







Figure 1

5. In this part of the activity, you will mark the location of the basketball as it moves during the video. By default, each time you mark the object’s location, the movie advances by just one frame. For this video analysis, it is better if the movie advances more quickly.

To change the setting, click or tap Advanced Video Options, . Change the Advance Frame setting to 2 or 5 frames, and then dismiss the window to save your changes.

6. Mark the location of the basketball as it moves during the video.
  - a. Click or tap Add, .
  - b. Decide where on the basketball you will mark its location (i.e., center, top, or other). It is important to be consistent when marking the location; always place the crosshairs on the same location on the ball.
  - c. Position the crosshairs at the chosen location on the ball, and then click to add the first point. **Note:** If you are using a phone or tablet, once you place the crosshairs you can click or tap anywhere in the video frame.
  - d. Continue this process as long as is desired. Should you wish to edit a point, click or tap Edit, . This allows you to move or delete a mismarked point.
7. Look at the graph window. If you hid it earlier, use View, , to bring it back. Vernier Video Analysis 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 *vs.* time graph of just one of these components at a time. To change which data are displayed, click or tap the vertical axis label and select from the listed options.

## EVALUATION OF DATA

1. Examine the graph of  $x$ -position ( $X$ ) *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, select each segment, one at a time, and fit separate straight lines to each portion of the graph that appears to be linear.
  - a. Click or tap one end of the linear data on the graph and drag across the segment to which you want to fit a line.
  - b. Click or tap Graph Tools, , and select Apply Curve Fit.
  - c. Choose Linear, and click or tap Apply. Repeat for a second segment of the graph, if desired.
2. Write the equation that describes the  $x$ -position *vs.* time behavior of the ball in each segment; be sure to include units.
3. Based on what you have learned in previous experiments, 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 ( $Y$ ) *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. Based on what you have learned in previous experiments, 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. Fit a straight line to the first 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 force(s) acting on it after it was launched.

## PROCEDURE

### Part 2 Production and analysis of your own video

You will need either a digital camera or other device capable of recording video; it can be the same device running Vernier Video Analysis. Keep the following tips in mind when you shoot your video.

- It is best to have a plain background that provides sufficient contrast with the projectile. Good lighting is essential; recording outside on a cloudy day will provide better light than recording inside.
- Set up the device on a tripod so that it is pointed squarely at the background, and so that the plane of motion is perpendicular to the view.
- Position the camera as far from the plane of motion as is practical in order to reduce problems with scaling and parallax. Use the zoom feature to fill the screen with the motion.
- The object used for scaling must be in the same plane as the motion of the projectile (see Figure 2).

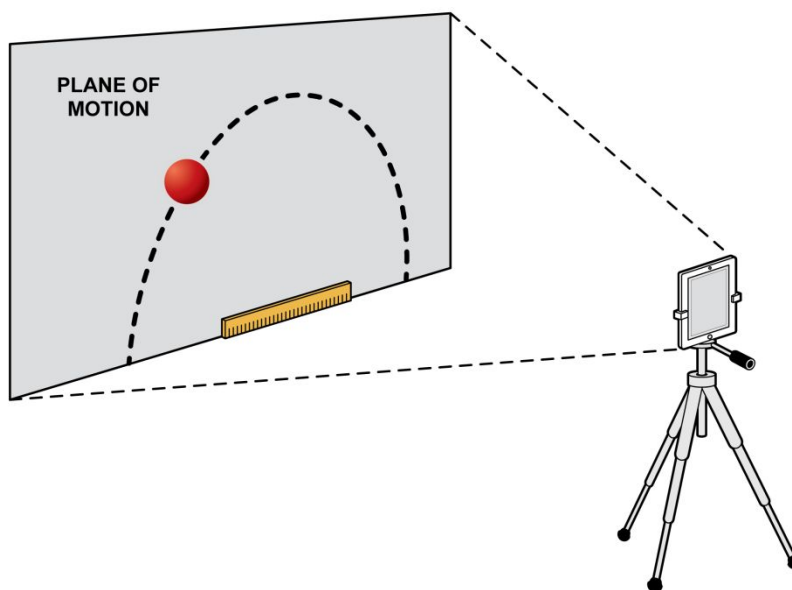


Figure 2

- Once you have captured your video, transfer the video to the device you will use for the analysis, if necessary. If you have captured more video than you need, trim the video to contain just the motion you plan to analyze.

## EVALUATION OF DATA

Perform the evaluation of data as you did with the video provided to you in Part 1.

## EXTENSIONS

1. Suppose that, in the shooting of your video, 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 the acceleration of gravity 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.
2. Repeat the production and video analysis of a projectile, but this time use an extended body (i.e., an object that cannot be readily modeled by a point-particle). Consider carefully how best to mark the position of such an object during its motion. Interpret your position vs. time and velocity vs. time graphs as you did for Parts 1 and 2.