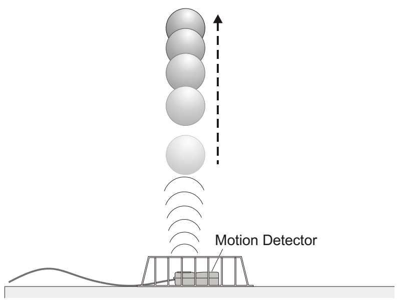
Computer
6

Ball Toss

When a juggler tosses a ball straight upward, the ball slows down until it reaches the top of its path. The ball then speeds up on its way back down. A graph of its velocity *vs.* time would show these changes. Is there a mathematical pattern to the changes in velocity? What is the accompanying pattern to the position *vs.* time graph? What would the acceleration *vs.* time graph look like?

In this experiment, you will use a Motion Detector to collect position, velocity, and acceleration data for a ball thrown straight upward. Analysis of the graphs of this motion will answer the questions asked above.



OBJECTIVES

- Collect position, velocity, and acceleration data as a ball travels straight up and down.
- Analyze position *vs.* time, velocity *vs.* time, and acceleration *vs.* time graphs.
- Determine the best-fit equations for the position *vs.* time and velocity *vs.* time graphs.
- Determine the mean acceleration from the acceleration *vs.* time graph.

PRELIMINARY QUESTIONS

1. Consider the motion of a ball as it travels straight up and down in freefall. Sketch your prediction for the position *vs.* time graph. Describe in words what this graph means.

2. Sketch your prediction for the velocity *vs.* time graph. Describe in words what this graph means.

3. Sketch your prediction for the acceleration *vs.* time graph. Describe in words what this graph means.

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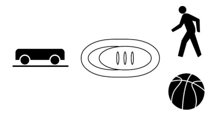
PROCEDURE



1. Connect the Vernier Motion Detector to a USB port on the computer. Set the Motion Detector sensitivity switch to Ball/Walk.

2. Place the Motion Detector on the table pointing up.

3. Open the file “06 Ball Toss” from the *Physics with Vernier* folder.

4. Collect data. During data collection you will toss the ball straight upward above the Motion Detector and let it fall back toward the Motion Detector. It may require some practice to collect clean data. To achieve the best results, keep in mind the following tips:
   - Hold the ball approximately 0.3 m directly above the Motion Detector when you start data collection.
   - A toss so the ball moves from 0.3 m to 1.0 m above the detector works well.
   - After the toss, catch the ball at a height of 0.3 m above the detector and hold it still until data collection is complete.
   - Use two hands and pull your hands away from the ball after it starts moving so they are not picked up by the Motion Detector.

   When you are ready to collect data, click ▶ Collect (or press the spacebar) to start data collection and then toss the ball as you have practiced.

5. Examine the position *vs.* time graph. Repeat Step 4 if your position *vs.* time graph does not show an area of smoothly changing position. Check with your instructor if you are not sure whether you need to repeat the data collection.

ANALYSIS

1. Print or sketch the three motion graphs—*ask your teacher for how best to do this*. The graphs you have recorded are fairly complex and it is important to identify different regions of each graph. Click Examine, , and move the mouse across any graph to answer the following questions. Record your answers directly on the printed or sketched graphs.
   a. Identify the region when the ball was being tossed but still in your hands:
      - Examine the velocity *vs*. time graph and identify this region. Label this on the graph.
      - Examine the acceleration *vs*. time graph and identify the same region. Label the graph.

   b. Identify the region where the ball is in free fall:
      - Label the region on each graph where the ball was in free fall and moving upward.
      - Label the region on each graph where the ball was in free fall and moving downward.

   c. Determine the position, velocity, and acceleration at specific points.
      - On the velocity *vs*. time graph, decide where the ball had its maximum velocity, just as the ball was released. Mark the spot and record the value on the graph.
      - On the position *vs*. time graph, locate the maximum height of the ball during free fall. Mark the spot and record the value on the graph.
      - What was the velocity of the ball at the top of its motion (farthest from detector)?
      - What was the acceleration of the ball at the top of its motion (farthest from detector)?

DATA TABLE

Curve fit parameters	A	B	C
Distance ($Ax^2 + Bx + C$)			
Velocity ($Ax + B$)			XXXXXXXXXXX
Average acceleration		XXXXXXXXXXX	XXXXXXXXXXX

2. The motion of an object in free fall is modeled by $y = ½\, gt^2 + v_0t + y_0$ where y is the vertical position, g is the magnitude of the free-fall acceleration, t is time, and v_0 is the initial velocity. This is a quadratic equation whose graph is a parabola. Your graph of position *vs.* time should be parabolic. To fit a quadratic equation to your data, click and drag the mouse across the portion of the position *vs.* time graph that is parabolic, highlighting just the free-fall portion.

   Click Curve Fit, , select Quadratic fit from the list of models and click Try Fit. Examine the fit of the curve to your data and click OK to return to the main graph.

3. Does the coefficient (A) of the t^2 term in the curve fit match ½ g *(i.e. 4.90 m/s²)*?

4. What does a linear segment of a velocity *vs.* time graph indicate? What is the significance of the slope of that linear segment?

5. The graph of velocity *vs.* time should be linear. To fit a line to this data, click and drag the mouse across the free-fall region of the motion. Click Linear Fit, .

6. Does the coefficient of the t term in the fit match the accepted value for g *(9.80 m/s²)*?

7. The graph of acceleration *vs.* time should appear to be more or less constant. Click and drag the mouse across the free-fall section of the motion and click Statistics, .

8. Does the mean acceleration match the values of g found in Steps 3 and 6?

9. List some plausible reasons (plural) why your values for the ball's acceleration may be different from the accepted value for g.

EXTENSIONS

1. Determine the consistency of your acceleration values and compare your measurement of *g* to the accepted value of *g*. Do this by repeating the ball toss experiment five more times. Each time, fit a straight line to the free-fall portion of the velocity graph and record the slope of that line. Average your six slopes to find a final value for your measurement of *g*. Does the variation in your six measurements explain any discrepancy between your average value and the accepted value of *g*?

2. The ball used in this lab is large enough and light enough that a buoyant force and air resistance may affect the acceleration. Perform the same curve fitting and statistical analysis techniques, but this time analyze each half of the motion separately. How do the fitted curves for the upward motion compare to the downward motion? Explain any differences.

3. Perform the same lab using a beach ball or other very light, large ball. See the questions in Analysis Question 1.

4. Use a smaller, more dense ball where buoyant force and air resistance will not be a factor. Compare the results to your results with the larger, less dense ball.

5. Instead of throwing a ball upward, drop a ball and have it bounce on the ground. (Position the Motion Detector above the ball.) Predict what the three graphs will look like, then analyze the resulting graphs using the same techniques as this lab.

6. Repeat your quadratic and linear curve fits to the position graphs but use the time offset option in the general curve fit dialog. Interpret the constant and linear terms of the quadratic fit. What do they signify? What are the units of each term?

7. Repeat the linear fit to the velocity graph but use the general Curve Fit, . In that dialog, choose the linear fit and enable the time offset option. Interpret the y-intercept of the linear fit. What does it signify? What are its units?