DataQuest
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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 distance *vs.* time graph? What would the acceleration *vs.* time graph look like?

In this experiment, you will use a Motion Detector to collect distance, 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 the position *vs.* time, velocity *vs.* time, and acceleration *vs.* time graphs.
- Determine the best-fit equations for the distance *vs.* time and velocity *vs.* time graphs.
- Determine the mean acceleration from the acceleration *vs.* time graph.

MATERIALS

TI-Nspire handheld **or**
computer and TI-Nspire software
CBR 2 **or** Go! Motion **or**
Motion Detector and data-collection interface
volleyball or basketball

PRE-LAB QUESTIONS

1. Think about the changes in motion a ball will undergo as it travels straight up and down. Make a sketch of your prediction for the position *vs.* time graph. Describe in words what this graph means.

2. Make a sketch of your prediction for the velocity *vs.* time graph. Describe in words what this graph means.

3. Make a sketch of your prediction for the acceleration *vs.* time graph. Describe in words what this graph means.

PROCEDURE

1. Place the Motion Detector on a table or chair, away from other objects.
2. If your Motion Detector has a switch, set it to Normal. Connect the Motion Detector to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer. (If you are using a CBR 2 or Go! Motion, you do not need a data-collection interface.)

3. Set up data collection.
   a. Choose New Experiment from the Experiment menu.
   b. Choose Collection Setup from the Experiment menu. Enter **25** as the rate in samples/second. The number of points collected should be 126.
   c. Select the Strip Chart option
   d. Select OK.

4. Collect the data.
   a. *This step may require some practice.* Hold the ball in two hands about 0.5 m above the motion detector. Toss the ball straight upward above the Motion Detector and let it fall back toward the Motion Detector. Be sure to pull your hands away from the ball after it starts moving so they are not picked up by the Motion Detector. A toss that goes to about 1.0 m above the Motion Detector works well.
   b. Have your partner start data collection (▶). **Note:** Data will be collected until you stop data collection but only the last 5 seconds of data will be retained.
   c. Toss the ball as described in Step a. Continue tossing until you have one good toss.
   d. Have your partner stop data collection (■) before any of the data from your desired toss is discarded.
   e. Check with your instructor if you are not sure whether you need to repeat the data collection. If necessary, repeat Steps b–d until you have the desired data.

5. Modify your graph to show only your desired toss.
   a. From the position *vs*. time graph, select a region of data that includes the desired toss. The region should be about 1.5 seconds in duration and included points both before and after the toss.
   b. Choose Strike Data from the Data menu, then select the Outside Selected Region option.
   c. Check with your instructor if you are not sure if your selected region is appropriate for the analysis of the data. If necessary, restore your data and select the region again.

6. Use Data Markers to identify the following points on your position vs. time graph.
   - The point where you started to toss the ball.
   - The point where the ball leaves your hand.
   - The point where the ball reaches its maximum height.
   - The point where the ball is first caught.
   - The point where the ball comes to rest in your hands.

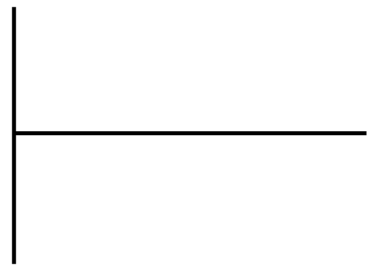
   a. To add a data marker, click on the graph and use ► and ◄ to locate the points.
   b. Move your cursor over the Graph View details box and launch the contextual menu (handheld – ctrl menu; computer – right-click). Select the Add Data Marker option.
   c. Add a brief description of the point in the text field.

7. Either print or sketch the three motion graphs. To display an acceleration *vs*. time graph, change the y-axis of the velocity or position graph to Acceleration.

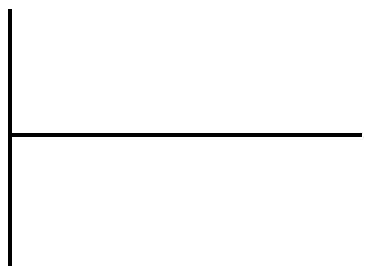
DATA

Position *vs*. Time

Velocity *vs*. Time



Acceleration *vs*. Time



PROCESSING THE DATA

1. Label these points directly on the printed or sketched graphs.
   a. Identify the region when the ball was being tossed but still in your hands.
      - Label this region on the velocity *vs*. time graph.
      - Label this same region on the acceleration *vs*. time 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 these specific points.
      - On the velocity *vs*. time graph, locate where the ball had its maximum velocity, after 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.

2. The motion of an object in free fall is modeled by $y = v_0t + ½\, gt^2$, where y is the vertical position, v_0 is the initial velocity, t is time, and g is the acceleration due to gravity (9.8 m/s^2). This is a quadratic equation whose graph is a parabola.

   Examine the position *vs*. time graph to see if it is a parabola in the region where the ball was in freefall. Now fit a quadratic equation to your data.

   a. If the data are not already selected, select the data points in the region where the ball was in freefall. Choose Curve Fit ► Position ► Quadratic from the Analyze menu.

   b. Record the parameters of the curve fit in the data table.

3. Display a graph of velocity *vs*. time. This graph should be linear in the region where the ball was in freefall. Fit a linear equation to your data in this region.
   a. Select the data points in the region that corresponds to when the ball was in freefall.
   b. Choose Curve Fit ► Velocity ► Linear from the Analyze menu.
   c. Record the parameters of the curve fit in the data table.
4. Examine the graph of acceleration *vs*. time. During free fall, the acceleration graph should appear to be more or less constant. Note that because the graph is automatically scaled to fill the screen vertically, small variations may appear large. A good way to analyze the acceleration data is to find the mean (average) of these data points.
   a. If the data are not already selected, select the data points in the region where the ball was in freefall. Choose Statistics ► Acceleration from the Analyze menu.
   b. Record the mean acceleration value in your data table.

	Analysis Parameters		
	A *or* M *or* Average	B	C
Distance ($Ax^2 + Bx + C$)			
Velocity ($Mx + B$)			
Average acceleration			

QUESTIONS

1. Based on your graphs, what was the velocity of the ball at the top of its motion? What was the acceleration of the ball at the top of its motion?
2. How closely does the coefficient of the x^2 term of the Quadratic fit of the position data compare to ½ *g*?
3. How closely does the coefficient of the x term of the linear fit of the velocity data compare to the accepted value of *g*?
4. How closely does the average acceleration of the free fall motion data compare to the accepted value for *g*?
5. List some reasons why your three measured 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 Extension 2 above.

4. Use a smaller, denser 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.