NSTA 2025
Philadelphia, PA

Exploring Motion with the Go Direct Motion Detector

Experiments

Graph Matching

- Go Direct® Motion Detector

Ball Toss

- Go Direct Motion Detector

Energy of a Tossed Ball

- Go Direct Motion Detector

Workshop Presenter

Josh Ence
physics@vernier.com

SCAN ME

Vernier Science Education • 888-VERNIER (888-837-6437)
info@vernier.com • www.vernier.com

Graph Matching

One of the most effective methods of describing motion is to plot graphs of position, velocity, and acceleration *vs.* time. From such a graphical representation, it is possible to determine in what direction an object is going, how fast it is moving, how far it traveled, and whether it is speeding up or slowing down. In this experiment, you will use a motion detector to determine this information by plotting a real-time graph of *your* motion as you move across the classroom.

The motion detector measures the time it takes for a high-frequency sound pulse to travel from the detector to an object and back. Using this round-trip time and the speed of sound, the distance to the object is calculated. This is the position of the object relative to the sensor. The change in position is then used to calculate the object's velocity and acceleration. All of this information can be displayed in a graph. A qualitative analysis of the graphs of your motion will help you develop an understanding of the concepts of kinematics.

OBJECTIVES

- Analyze the motion of a student walking across the room.
- Predict, sketch, and test position *vs.* time kinematics graphs.
- Predict, sketch, and test velocity *vs.* time kinematics graphs.

CHOOSE A METHOD

Method 1: Bluetooth Connection–Use Method 1 if you are using a mobile device, such as a tablet or a phone, and connecting to a Go Direct Motion via Bluetooth. You will hold the motion detector and measure your position and velocity relative to a wall.

Method 2: USB Connection–Use Method 2 if you are using a computer or Chromebook, and are connecting the motion detector via USB. You will measure your position and velocity relative to a stationary motion detector.

MATERIALS

Required for *both* Method 1 (Bluetooth connection) and Method 2 (USB connection)

Graphical Analysis app
Go Direct Motion
meter stick
masking tape

Required for Method 1 *only* (Bluetooth connection)

mobile device

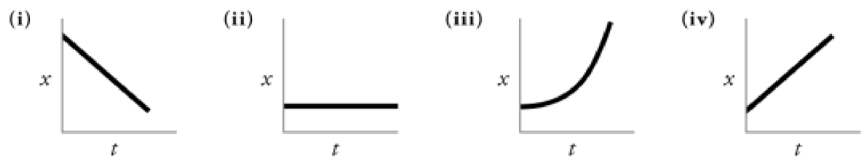
Required for Method 2 *only* (USB Connection)

computer or Chromebook

PRELIMINARY QUESTIONS

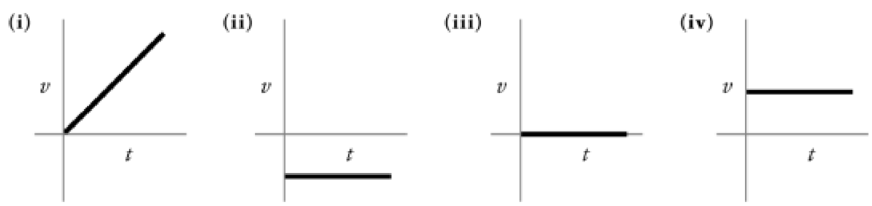
1. Below are four position *vs.* time graphs labeled (i) through (iv). Identify which graph corresponds to each of the following situations and explain why you chose that graph.

   a. An object at rest
   b. An object moving in the positive direction with a constant speed
   c. An object moving in the negative direction with a constant speed
   d. An object that is accelerating in the positive direction, starting from rest



2. Below are four velocity *vs.* time graphs labeled (i) through (iv). Identify which graph corresponds to each of the following situations. Explain why you chose that graph.

   a. An object at rest
   b. An object moving in the positive direction with a constant speed
   c. An object moving in the negative direction with a constant speed
   d. An object that is accelerating in the positive direction, starting from rest



PROCEDURE

Method 1 Bluetooth Connection

Part I Preliminary Experiments

1. Find an open area at least 2 m long in front of a wall. Use short strips of masking tape on the floor to mark distances of 0.5 m, 1 m, 1.5 m, and 2 m from the wall. You will be measuring your position from the motion detector in your hands to the wall.

2. Launch Graphical Analysis. Connect the motion detector to your mobile device.

3. Click or tap Mode to open Data Collection Settings. Change End Collection to 5 s. Click or tap Done.

4. Monitor the position readings and practice walking toward the wall holding the motion detector and mobile device. During data collection, the sensor portion of the motion detector should always point directly at the wall as shown in Figure 1. Sometimes you will have to walk backwards. Confirm that the position values make sense as you move back and forth.

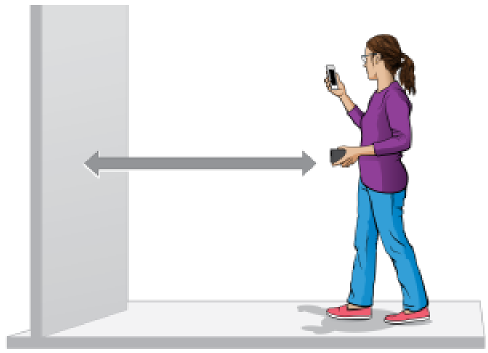


Figure 1

5. Make a graph of your motion while you walk away from the wall with constant velocity. To do this, stand about 0.5 m from the wall and click or tap Collect to start data collection. Slowly walk backward away from the wall after data collection begins.

6. Examine the graph. Sketch a prediction of what the position *vs.* time graph will look like if you walk faster. Check your prediction with the motion detector. Start data collection when you are ready to begin walking. **Note**: The previous data set is automatically saved.

Part II Position *vs.* Time Graph Matching

7. Click or tap Graph Options, 📈, and choose Add Graph Match. Choose Position. A position target graph is displayed for you to match.

8. Describe how you would walk to reproduce the target graph.

9. To test your prediction, choose a starting position. Start data collection, then walk in such a way that the graph of your motion matches the target graph on the screen.

10. If you were not successful, start data collection again when you are ready to begin walking. Repeat this process until your motion closely matches the graph on the screen. Export, print, or sketch the graph with your best attempt showing both the target graph and your motion data.

11. To perform a second position graph match, click or tap Graph Options, 📈, choose Add Graph Match, and then Position. Repeat Steps 8–10.

12. Answer the Analysis questions for Part II before proceeding to Part III.

Part III Velocity *vs.* Time Graph Matching

13. Graphical Analysis can also generate random target velocity graphs for you to match. Click or tap Graph Options, 📈, and choose Add Graph Match. Choose Velocity to view a velocity target graph.

14. Describe how you would walk to produce this target graph. Sketch or print a copy of the graph.

15. To test your prediction, choose a starting position and stand at that point. Start data collection, then walk in such a way that the graph of your motion matches the target graph. It is more difficult to match the velocity graph than the position graph.

16. If you were not successful, start data collection again when you are ready to start walking. Repeat this process until your motion closely matches the graph on the screen. Export, print, or sketch the graph with your best attempt showing both the target graph and your motion data.

17. To perform a second velocity graph match, click or tap Graph Options, 📈, choose Add Graph Match, and then Velocity. Repeat Steps 14–16.

18. Remove the masking tape from the floor.

19. Proceed to the Analysis questions for Part III.

Method 2 USB Connection with Computers or Chromebooks

Part I Preliminary Experiments

1. Place the motion detector so that it points toward an open space at least 2 m long. Use short strips of masking tape on the floor to mark distances of 0.5 m, 1 m, 1.5 m, and 2 m from the motion detector.

2. Launch Graphical Analysis. Connect the motion detector to your Chromebook or computer.

3. Click or tap Mode to open Data Collection Settings. Change End Collection to 5 s. Click or tap Done.

4. Monitor the position readings and practice walking toward the motion detector. Sometimes you will have to walk backwards. Confirm that the position values make sense as you move back and forth.

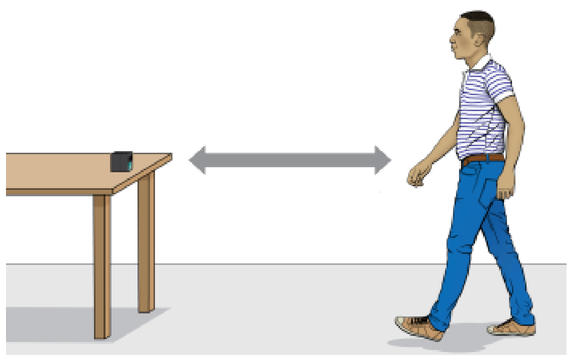


Figure 2

5. Make a graph of your motion while you walk away from the motion detector with constant velocity. To do this, stand about 0.5 m from the motion detector and click or tap Collect to start data collection. Slowly walk backward away from the motion detector after data collection begins.

6. Examine the graph. Sketch a prediction of what the position *vs.* time graph will look like if you walk faster. Check your prediction with the motion detector. Start data collection when you are ready to begin walking. **Note**: The previous data set is automatically saved.

Part II Position *vs.* Time Graph Matching

7. Click or tap Graph Options, 📈, and choose Add Graph Match. Choose Position. A position target graph is displayed for you to match.

8. Describe how you would walk to reproduce the target graph.

9. To test your prediction, choose a starting position. Start data collection, then walk in such a way that the graph of your motion matches the target graph on the screen.

10. If you were not successful, start data collection again when you are ready to begin walking. Repeat this process until your motion closely matches the graph on the screen. Export, print, or sketch the graph with your best attempt showing both the target graph and your motion data.

11. To perform a second position graph match, click or tap Graph Options, , choose Add Graph Match, and then Position. Repeat Steps 8–10.

12. Answer the Analysis questions for Part II before proceeding to Part III.

Part III Velocity *vs.* Time Graph Matching

13. Graphical Analysis can also generate random target velocity graphs for you to match. Click or tap Graph Options, , and choose Add Graph Match. Choose Velocity to view a velocity target graph.

14. Describe how you would walk to produce this target graph. Sketch or print the graph.

15. To test your prediction, choose a starting position and stand at that point. Start data collection, then walk in such a way that the graph of your motion matches the target graph. It is more difficult to match the velocity graph than the position graph.

16. If you were not successful, start data collection when you are ready to start walking again. Repeat the process until your motion closely matches the graph. Export, print, or sketch the graph with your best attempt showing both the target graph and your motion data.

17. To perform a second velocity graph match, click or tap Graph Options, , choose Add Graph Match, and then Velocity. Repeat Steps 14–16.

18. Remove the masking tape from the floor.

19. Proceed to the Analysis questions for Part III.

ANALYSIS

Part II Position *vs.* Time Graph Matching

1. Describe how you walked for each of the graphs that you matched.

2. Explain the significance of the slope of a position *vs.* time graph. Include a discussion of positive and negative slope.

3. What type of motion is occurring when the slope of a position *vs.* time graph is zero?

4. What type of motion is occurring when the slope of a position *vs.* time graph is constant?

5. What type of motion is occurring when the slope of a position *vs.* time graph is changing? Test your answer to this question using the motion detector.

Part III Velocity *vs.* Time Graph Matching

6. Describe how you walked for each of the graphs that you matched.
7. What type of motion is occurring when the slope of a velocity *vs*. time graph is zero?
8. What type of motion is occurring when the slope of a velocity *vs*. time graph is not zero? Test your answer using the motion detector.

EXTENSIONS

1. Create a graph-match challenge. Click or tap File, 🗋, and choose New Experiment. Click or tap Sensor Data Collection. Set up data-collection to end after 5 seconds. Click or tap View Options, ⊞, and choose 1 Graph. Click or tap Graph Options, ⇗, and choose Add Prediction. Use the Prediction tool to sketch a position *vs*. time graph. Click or tap Save. Challenge another student to match your graph. Have the other student challenge you in the same way.
2. Create a velocity *vs*. time challenge in a similar manner.

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.

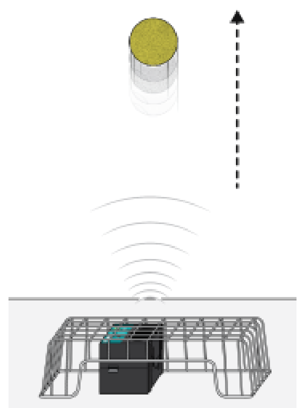


Figure 1

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.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis app
Go Direct Motion
volleyball **or** basketball
wire basket

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.

PROCEDURE

1. Launch Graphical Analysis. Connect the motion detector to your Chromebook, computer, or mobile device.

2. Place the motion detector on the floor and protect it by placing a wire basket over it.

3. 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 0.5 m directly above the motion detector when you start data collection.
   - A toss so the ball moves from 0.5 m to 1.0 m above the motion detector works well.
   - After the toss, catch the ball at a height of 0.5 m above the motion 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 or tap Collect to start data collection and then toss the ball as you have practiced.

DATA TABLE

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

ANALYSIS

1. Export, print, or sketch the three motion graphs. To display an acceleration *vs.* time graph, change the y-axis of the velocity graph to Acceleration. The graphs you have recorded are fairly complex and it is important to identify different regions of each graph. Record your answers directly on your copy of the graphs.

   a. Identify the region when the ball was being tossed but was 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 this on 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 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.
   - 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. The motion of an object in free fall is modeled by $y = \frac{1}{2} gt^2 + v_0t + y_0$ 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.

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

   a. Select the data in the region that corresponds to when the ball was in freefall.
   b. Click or tap Graph Options, for the position *vs.* time graph and choose Apply Curve Fit.
   c. Select Quadratic as the curve fit and click or tap Apply.
   d. Record the parameters of the curve fit in the data table.

3. How closely does the coefficient of the x^2 term in the curve fit compare to ½ g?

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. 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 in the region that corresponds to when the ball was in freefall.
   b. Click or tap Graph Options, for the velocity *vs.* time graph and choose Apply Curve Fit.
   c. Select Linear as the curve fit and click or tap Apply.
   d. Record the parameters of the curve fit in the data table.

6. How closely does the coefficient of the x term compare to the accepted value of g?

7. 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. Click or tap Graph Options, and choose View Statistics.
   b. Record the mean acceleration value in your data table.

8. How closely does the mean acceleration value compare to the values of *g* found in Steps 3 and 6?

9. List some reasons 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.

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.

Energy of a Tossed Ball

When a juggler tosses a ball straight upward, the ball slows down until it reaches the top of its path and then speeds up on its way back down. In terms of energy, when the ball is released it has kinetic energy, *KE*. As it rises during its free-fall phase it slows down, loses kinetic energy, and gains gravitational potential energy, *PE*. As it starts down, still in free fall, the stored gravitational potential energy is converted back into kinetic energy as the object falls.

If there is no work done by frictional forces, the total energy remains constant. In this experiment, we will see if this is true for the toss of a ball. We will study these energy changes using a motion detector.

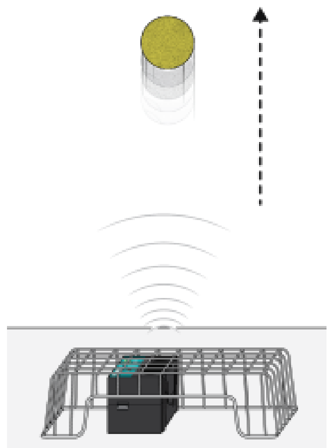


Figure 1

OBJECTIVES

- Measure the change in the kinetic and potential energies as a ball moves in free fall.
- See how the total energy of the ball changes during free fall.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis app
Go Direct Motion
volleyball, basketball, **or** other similar fairly heavy ball
wire basket

PRELIMINARY QUESTIONS

For each question, consider the free-fall portion of the motion of a ball tossed straight upward, starting just as the ball is released to just before it is caught. Assume that there is very little air resistance.

1. What form or forms of energy does the ball have while momentarily at rest at the top of the path?
2. What form or forms of energy does the ball have while in motion near the bottom of its path?
3. Sketch a graph of velocity *vs.* time for the ball.
4. Sketch a graph of kinetic energy *vs.* time for the ball.
5. Sketch a graph of potential energy *vs.* time for the ball.
6. If there are no frictional forces acting on the ball, how is the change in the ball's potential energy related to the change in kinetic energy?

PROCEDURE

1. Measure and record the mass of the ball you plan to use in this experiment.
2. Set up the motion detector and Graphical Analysis.
   a. Launch Graphical Analysis.
   b. Connect the motion detector to your Chromebook, computer, or mobile device.
   c. In this experiment, you need graphs of position *vs*. time and velocity *vs*. time. If only one graph is displayed, click or tap View Options, ⊞, and choose 2 Graphs.
3. Place the motion detector on the floor or table, and protect it by placing a wire basket over it.
4. In this step, you will toss the ball straight upward above the motion detector and let it fall back toward the motion detector. This step may require some practice.
   a. Hold the ball directly above and about 0.25 m from the motion detector. Use two hands.
   b. Click or tap Collect to start data collection.
   c. Wait one second, then toss the ball straight upward. Move your hands out of the way after you release it. A toss of 0.5 to 1.0 m above the motion detector works well. You will get the best results if you catch and hold the ball when it is about 0.5 m above the motion detector.
5. After data collection is complete, graphs of position *vs.* time and velocity *vs.* time are displayed. Repeat Step 4 if your position *vs.* time graph does not show a region of smoothly changing distance. Check with your instructor if you are not sure whether you need to repeat data collection. To repeat data collection, click or tap Collect to start data collection when you are ready to toss the ball.

DATA TABLE

Mass of the ball (kg)

Position	Time (s)	Height (m)	Velocity (m/s)	*PE* (J)	*KE* (J)	*TE* (J)
After release						
Between release and top						
Top of path						
Between top and catch						
Before catch						

ANALYSIS

1. Click or tap the graphs to examine the free-fall portion of the data and answer the following questions.

   a. Identify the portion of each graph where the ball had just left your hands and was in free fall. Determine the height and velocity of the ball at this time. Enter your values in your data table.

   b. Identify the point on each graph where the ball was at the top of its path. Determine the time, height, and velocity of the ball at this point. Enter your values in your data table.

   c. Find a time where the ball was moving downward, just before it was caught. Measure and record the height and velocity of the ball at that time.

   d. Choose two more points approximately halfway in time between the three recorded so far.

   e. For each of the five points in your data table, calculate the Potential Energy (*PE*), Kinetic Energy (*KE*), and Total Energy (*TE*). Use the position of the motion detector as the zero of your gravitational potential energy.

2. How well does this table you have just completed show conservation of energy? Explain.

   You can also graph the ball's energy at all the measured times, instead of just the five in the data table. Using the position data in the equation *mgh*, you can store gravitational potential energy at each moment in a new column. Using the velocity data in the equation

   $$KE = \frac{1}{2}mv^2,$$

   you can store the ball's kinetic energy in another new column. Finally, you can find the total mechanical energy at each moment by finding the sum of the potential and kinetic energies and storing the data in a third new column. You will do this in the upcoming steps.

3. Calculate the ball's kinetic energy, storing the result in a new column.

   a. Click or tap More Options, ⊟, in the Velocity column header in the table. Then, choose Add Calculated Column.
   b. Enter **KE** as the Name and **J** as the Units.
   c. Click or tap Insert Expression and choose A*X^B because this has the same form as

   $$KE = \frac{1}{2}mv^2$$

   d. Select Velocity as the Column for X.
   e. For the Parameter A value, enter the mass of your ball in kilograms multiplied by **0.5**.
   f. For the Parameter B value, enter **2**.
   g. Click or tap Apply.
   h. To display a single graph and the table, click or tap View Options, ⊞, and choose Graph and Table. If necessary, change the y-axis to KE in order to display a graph of kinetic energy (*KE*) *vs.* time.

   Inspect your kinetic energy *vs.* time graph for the free-fall flight of the ball. Explain its shape and then print or sketch the graph.

4. Calculate the ball's gravitational potential energy (*PE*) using *mgh*, where the height, *h*, comes from your distance data, storing the result in a new column.

   a. Click or tap More Options, ⊟, in the Position column header in the table. Then, choose Add Calculated Column.
   b. Enter **PE** as the Name and **J** as the Units.
   c. Click or tap Insert Expression and choose A*X+B because this has the same form as *mgh* (you will enter 0 for B).
   d. Select Position as the Column for X.
   e. For the Parameter A value, enter the mass of the ball in kilograms multiplied by **9.8**.
   f. For the Parameter B value, enter **0**.
   g. Click or tap Apply. If necessary, change the y-axis to PE in order to display a graph of potential energy (*PE*) *vs.* time.

   Inspect your potential energy *vs.* time graph for the free-fall flight of the ball. Explain its shape and then print or sketch the graph.

5. Compare your energy graph predictions (from the Preliminary Questions) to the real data for the ball toss.

6. Calculate the ball's total energy, *TE* = *KE* + *PE*, and store the result in a third new column.

   a. Click or tap More Options, ⊟, in the KE column header in the table. Then, choose Add Calculated Column.
   b. Enter **TE** as the Name and **J** as the Units.
   c. Click or tap Insert Expression and choose A*X + B*Y.

d. Select KE (J) as the Column for X.

e. Select PE (J) as the Column for Y.

f. Enter **1** for both Parameters A and B.

g. Click or tap Apply. If necessary, change the y-axis to TE in order to display a graph of total energy (*TE*) *vs.* time.

7. To display all three energy plots on the same graph, click or tap the y-axis and select PE and KE (ensure that TE is still selected). Dismiss the box to view the graph.

8. What do you conclude from the total energy *vs.* time graph about the total energy of the ball as it moved up and down in free fall? Does the total energy remain constant? Should the total energy remain constant? Why? If it does not, what sources of extra energy are there or where could the missing energy have gone?

EXTENSIONS

1. What would change in this experiment if you used a very light ball, like a beach ball?

2. What would happen to your experimental results if you entered the wrong mass for the ball in this experiment?

3. Try a similar experiment using a bouncing ball. Mount the motion detector high and pointed downward so it can follow the ball through several bounces.