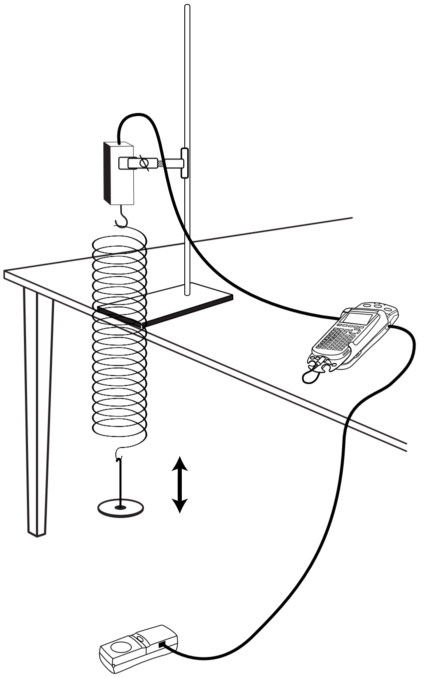
Activity

8

Spring Thing: Newton's Second Law

If you push or pull an object (and yours is the only force on the object), the way it changes its motion depends on two things: the *force* you apply, and the object's *mass*. Sir Isaac Newton was the first to recognize that an object's acceleration is directly proportional to the total force applied (the larger the force, the more rapidly it speeds up or slows down), and inversely proportional to its mass (massive objects have a greater tendency to resist efforts to make them speed up or slow down). Stated mathematically, that is $F = ma$ where F is the force applied to the object, m is its mass, and a is its acceleration. This expression is known as Newton's second law.

In this activity, you will use a force sensor and a motion detector to record force and acceleration data for an object (called the *bob*) moving up and down hanging from a light spring. These data will be used to test the mathematical relationship of Newton second law.



OBJECTIVES

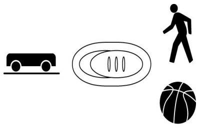
- Collect force and motion data for a bob moving at the end of a light spring.
- Compare the force and acceleration data to test Newton's second law.
- Use Newton's second law to estimate the mass of an object.

MATERIALS

TI-83 Plus or TI-84 Plus graphing calculator
data-collection interface
Vernier Force Sensor
Motion Detector
EasyData application
ring stand
light spring or Slinky™
standard mass hanger

PROCEDURE

1. Prepare the Force Sensor and Motion Detector for data collection.
   a. Turn on your calculator and connect it to the data-collection interface.
   b. Set the Force Sensor range switch to 10 N.
   c. Connect the Force Sensor to CH 1 of the data-collection interface.
   d. Open the pivoting head of the Motion Detector. If your Motion Detector has a sensitivity switch, set it to Normal as shown.
   e. Connect the Motion Detector to the DIG/SONIC port of the data-collection interface. (If there is more than one DIG/SONIC port, connect it to the first one.)



2. Set up your apparatus.
   a. Attach the Force Sensor to a ring stand so that the sensor hangs well over the edge of the table. The hook must be pointing straight down.
   b. Hang the spring from the hook, and hang the bob from the spring.
   c. Position the Motion Detector directly under the bob so that the disc is pointing upward. When the bob is at rest, the distance from the bob to the detector should be between 0.7 and 1.0 m.
3. Set up EasyData for data collection.
   a. Start the EasyData application, if it is not already running.
   b. Select **File** from the Main screen, and then select **New** to reset the application.
4. In this activity you only want to measure the force it takes to accelerate the bob, as opposed to just support it while hanging motionless. To account for the weight of the spring and bob, you need to zero the force sensor:
   a. Select **Setup** from the Main screen, and then select **Zero…**
   b. Select **CHs**, and then select **FORCE**.
   c. Wait until the bob stops moving. Select **Zero** to zero the Force Sensor. All subsequent force measurements will be referenced from the current force on the sensor.
5. You are now ready to collect distance, velocity, acceleration, and force versus time data.
   a. Lift the bob no more than 10 cm and release it. Wait until the bob is moving up and down smoothly.
   b. Select **Start** to begin data collection, which will run for five seconds.
6. When data collection is complete, a graph of force versus time will be displayed. To view the distance versus time graph, select **Plots** and then select **Dist(m) vs Time**. You should see a smooth sinusoidal function. If you want to repeat data collection, select **Main**, and repeat Step 5.

ANALYSIS

1. View each of the force, distance, velocity and acceleration graphs in turn by selecting Plots and selecting the desired graph from the menu. Pay particular attention to the times that each function reaches a maximum, minimum and a zero.

⇒ Sketch these graphs in the spaces shown in Question 1 on the *Data Collection and Analysis* sheet.

When you are done sketching, select Main. Exit EasyData by selecting Quit from the Main screen and then selecting OK.

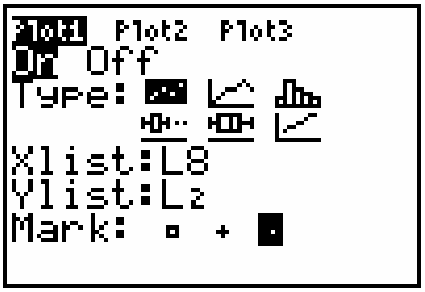
⇒ Answer Questions 2-4 on the *Data Collection and Analysis* sheet.

2. The graphs are all a quantity versus time. However, that is not the only way the data can be graphed. To predict what a graph of force versus acceleration would look like, consider any specific time on your graphs. What values do the force and acceleration have? Imagine plotting a point on a new force versus acceleration graph using the values at that particular time. Now consider other times. As you build up the graph using all times, what would the resulting graph look like?

⇒ Answer Question 5 on the *Data Collection and Analysis* sheet.

3. Display a new graph of force versus acceleration.
   a. Press 2nd [STAT PLOT] and press ENTER to select Plot 1.
   b. Change the Plot1 settings to match the screen shown here. Press ENTER to select any of the settings you change.

      Enter L8 by pressing 2nd [LIST] and scroll down to highlight L8. Press ENTER to paste L8 to the Plot1 settings screen.
   c. Press ZOOM and then select ZoomStat (use cursor keys to scroll to ZoomStat) to draw a graph with the *x* and *y* ranges set to fill the screen with data.


Plot1 Plot2 Plot3
On Off
Type:
Xlist:L8
Ylist:L_2
Mark: □ + ■

⇒ Answer Questions 6 and 7 on the *Data Collection and Analysis* sheet.

4. You can fit a model of $y = mx$ to the force versus acceleration data using trial and error for the parameter *m*.
   a. Press Y=.
   b. Press CLEAR to remove any existing equation.
   c. Enter M∗X on the Y_1 line.
   d. Press 2nd [QUIT] to return to the home screen.

5. Set a value for the parameter *m*, and then look at the resulting graph. To obtain a good fit, you will need to try several values for *m*. Use the steps below to store different values to the parameter *m*. Start with m = 0.2.
   a. Enter a value for the parameter *m*. Press STO▸ M ENTER to store the value in the variable M.
   b. Press GRAPH to see your data with the model graph superimposed.
   c. Press 2nd [QUIT] to return to the home screen.

d. Repeat Steps a through c using different values. Experiment until you find one that provides a good fit for the data. Record the optimized value of m in the Data Table.

⇒ Answer Questions 8–10 on the *Data Collection and Analysis* sheet.

EXTENSION

For a spring, the force *F* applied by the spring, and the amount of stretch, *x*, are related by Hooke's law, or $F = -kx$. The constant *k* is called the spring constant. The spring constant measures the stiffness of the spring—a stiff spring with a large *k* applies a large force when it is stretched or compressed even a little bit. An example of a spring with a large *k* is a suspension spring on an automobile, while the spring in a retractable pen has a small *k*.

Make a plot of force (`L2`) versus position (`L6`) and determine the value of *k* that fits the data. What are the units of *k*?

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DATA COLLECTION AND ANALYSIS

Name ______________________________

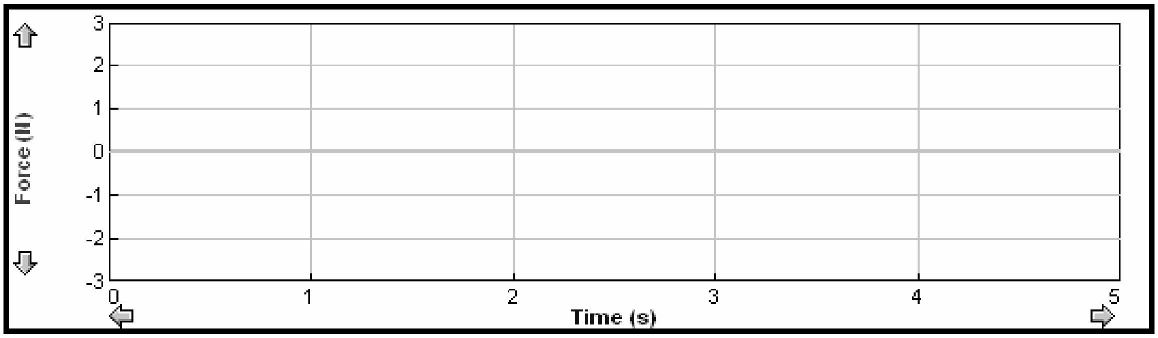
Date ______________________________

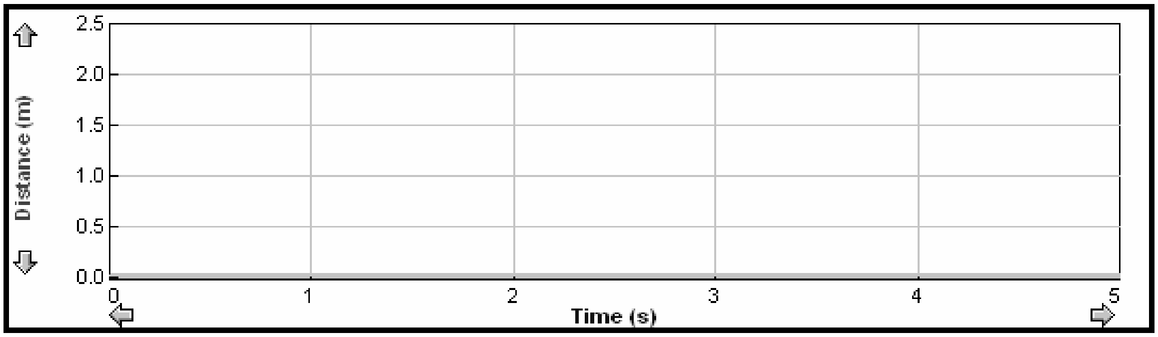
DATA TABLE

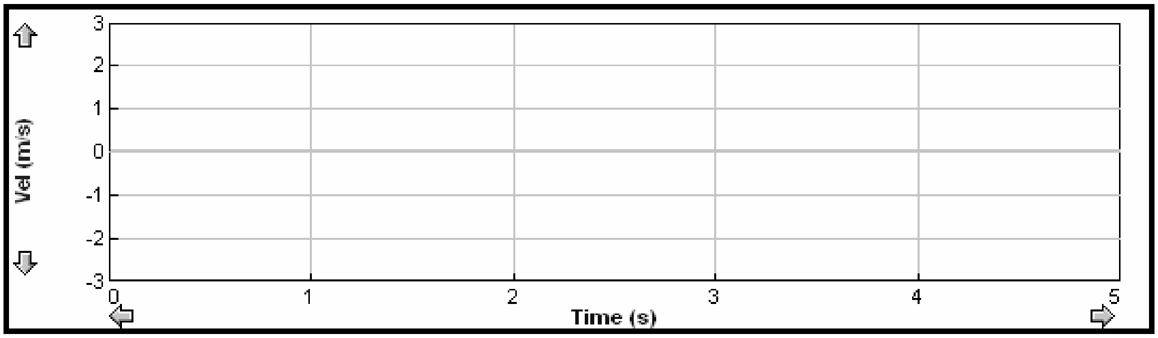
m	
bob mass (kg)	

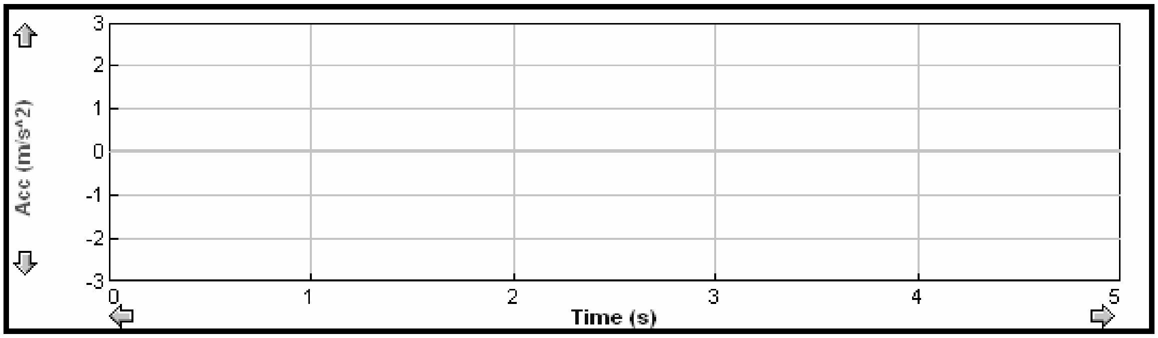
QUESTIONS

1. In the spaces below, make a sketch of each of the force, distance, velocity and acceleration graphs. You may want to start your sketch by marking the times of each maximum, minimum and zero crossings on the graph. Then you can fill in the remaining details of the graphs.









2. Inspect the graphs of distance, velocity and acceleration versus time. Where is the bob located when acceleration is greatest? What is the velocity at that time?

3. Can the velocity be zero at the same time that the acceleration is non-zero? Explain why or why not.

   Do you have evidence from the graphs? ____

4. Inspect the four graphs. All four should be variations on a sinusoidal function, with varying phases and amplitudes. Which two graphs share the same phase? That is, which two are always in step? **Hint:** Which two variables are addressed by Newton's second law?

5. As you build up the graph of force versus acceleration using all times, what would the resulting graph look like?

6. What does the graph tell you about the way force and acceleration are related? Is the graph consistent with your prediction in Step 5?

7. Is the data consistent with Newton's second law, which reads $F = ma$. That is, Newton's second law says that force and acceleration are directly proportional. Does your graph show proportionality between force and acceleration?

8. What is the mass of the bob? Enter this value in the Data Table above, in units of kg.

9. How does the mass of your bob compare to the optimized value of the parameter *m* for the force versus acceleration graph? In what way does this comparison of values confirm Newton's second law?

10. It is likely that the value of the parameter *m* is somewhat larger than the mass of the bob. How can you explain this difference? **Hint:** Is anything bouncing up and down with the bob?