Falling Down

About the Lesson

Galileo found that cannonballs of different mass hit the ground at the same time. This activity focuses on falling coffee filters that have more air resistance than cannonballs. As a result, students will use height-time graphs to determine the coordinates of two points and to calculate the average speed that the coffee filter travelled at the terminal velocity.

Vocabulary

- average speed
- acceleration
- terminal velocity
- air resistance
- force
- gravity
- mass

Teacher Preparation and Notes

- Students need to have some understanding of speed and acceleration. Showing a YouTube video, Terminal Velocity on a Sky Diver, may help students understand the forces involved with a free falling object. (https://www.youtube.com/watch?v=EabUUrZFnFE)
- The activity is written using the setup at the top right (the filter falling down on the CBR 2) that can be done by 2 students. The Going Further questions describe the set up at the bottom right that may require 3 students to do effectively.

Activity Materials

- Compatible TI Technologies:

  TI-84 Plus*
  TI-84 Plus Silver Edition*
  TI-84 Plus C Silver Edition
  TI-84 Plus CE

** with the latest operating system (2.55MP) featuring MathPrint™ functionality.*

- CBR 2™ motion sensor unit with mini-USB connecting cable
- Vernier EasyData® App
- 6 large basket style coffee filters for each group

Set up options:

Tech Tips:

- This activity includes screen captures taken from the TI-84 Plus CE. It is also appropriate for use with the rest of the TI-84 Plus family. Slight variations to these directions may be required if using other calculator models.
- Watch for additional Tech Tips throughout the activity for the specific technology you are using.
- Access free tutorials at http://education.ti.com/calculators/pd/US/Online-Learning/Tutorials
- Any required calculator files can be distributed to students via handheld-to-handheld transfer.

Lesson Files:

- Falling_Down_Student.pdf
- Falling_Down_Student.doc

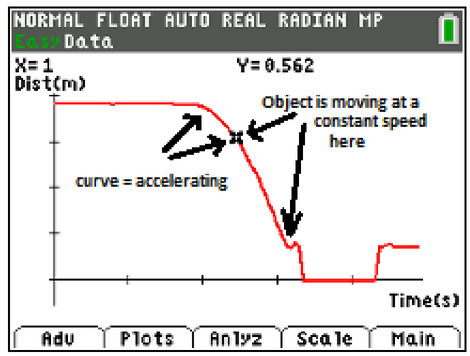
Tech Tip: While using the Vernier EasyData™ App, the tabs at the bottom of the screen indicate menus that are accessed by pressing the calculator key directly below it. A frequent example is shown below:

Introduction

When Galileo supposedly dropped the cannonballs of different masses, did the balls reach terminal velocity before they hit the ground? If the cannonballs did not reach terminal velocity before reaching the ground, then the two masses had been experiencing the same acceleration (due to the force of gravity) and would have hit the ground at practically the same time. See the Looking at the Results and Going Further questions for more thoughts on this.

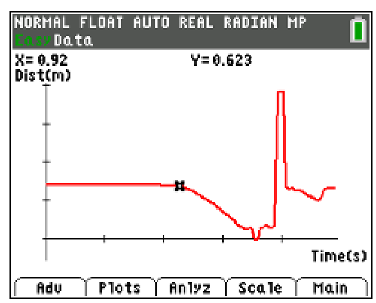
Teaching Notes

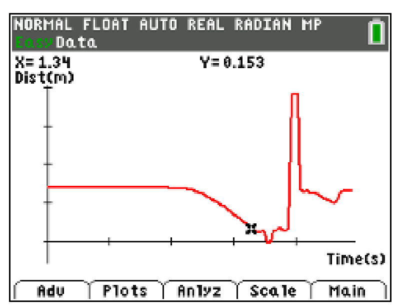
- In a distance-time graph, acceleration is happening where the graph curves. See the curved portion of the graph to the right. The portions of the distance-time graph that are straight lines indicate the object is travelling at a constant velocity.



Collecting the Data

The students will be making six height-time graphs. The students' activity explains how to change the experiment length to 2 seconds. When dropping the coffee filter(s) on the CBR 2, the last portion of the graph will look strange with spikes or plateaus. Students need to interpret the graph and identify the portion of the graph where the filter(s) are moving at a constant velocity. Using the arrow keys to move through the data, the example to the right is for 4 coffee filters. The terminal velocity is reached between 0.92 s and 1.34 s. The filters fell from 0.623 m to 0.153 meters in that time. The average speed $\frac{0.470\ m}{0.42\ s} = 1.119\ m/s$. When the coffee filter is less than 0.15 meters from the CBR 2, the measurements are generated randomly making strange-looking spikes and plateaus in the last part of the graph.





Looking at the Results

1. Sample data from the 6 trials:

Mass (# of filters)	Distance (m)	Time (s)	Average Speed (m/s)
1	0.510	0.72	0.708
2	0.534	0.58	0.921
3	0.540	0.5	1.08
4	0.470	0.42	1.119
5	0.419	0.30	1.397
6	0.4536	0.30	1.453

2. Describe any patterns that you see relating the mass with the speed in the data table.

   Student answers will vary.

   Sample response: As the mass increases, the average speed increases.

3. If one object travels at a higher average speed at terminal velocity than another object and both are dropped simultaneously from the same height, will the object with the higher average speed always reach the ground first? Justify your answer.

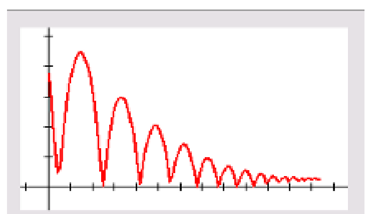
   Student answers will vary.

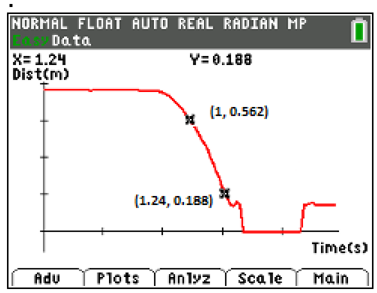
   Sample response: Yes. The time required to reach the ground will always be the distance traveled divided by the average speed. Since the distance will be the same for both objects, dividing by a larger number, in this case the average speed, will yield a smaller time value.

4. Which one shows an object that achieved terminal velocity? How do you know?

   Student answers will vary.

   Sample response: The bouncing object in the first plot does not appear to reach terminal velocity. The second plot shows that the object traveled at a constant speed between about 1 second and 1.24 seconds. In that section of the plot, the distance changes at a constant rate making the graph a straight line.

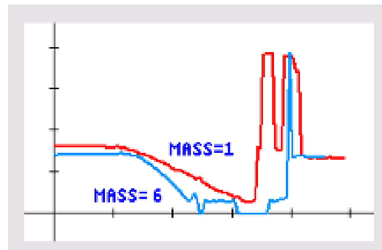




5. Think about how quickly the coffee filters reach terminal velocity as compared to Galileo's cannonballs. Galileo concluded that cannonballs of different mass would hit the ground at the same time. Did your results with the filters contradict Galileo's conclusions? Explain your answer carefully.

   Student answers will vary.

   Sample response: The data table shows that as mass increases the average speed of the terminal velocity increases which means that the heavier object would reach the ground before the lighter object having equal air resistance. But this probably does not contradict Galileo, since the cannonballs require a much longer distance to obtain terminal velocity. It could be that Galileo's cannonballs had not yet achieved terminal velocity and so hit the ground at practically the same time (considering the difference in drag coefficient and cross-sectional area). At least Galileo saw that gravity was the acceleration for all falling objects. This was a milestone in the field of physics. It is not known if Galileo actually performed the experiment or not.

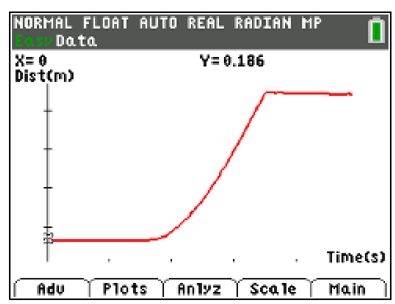


Going Further

1. Suppose instead of dropping the filters onto the CBR 2, one person in your group held the CBR 2 at eye level pointing downward. After the CBR 2 starts, a second student releases the filter (concave side up) from about 0.15 m below the CBR 2. Sketch what the height-time graph would look like.

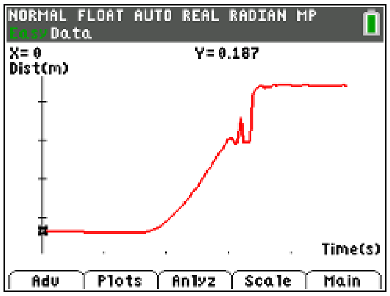
   Student answers will vary.

   Sample response: When the data is collected with the CBR 2 facing downward and the coffee filters released from about 0.15 m below the CBR 2, the graph will start low and end high. The first horizontal section is before the filters are released. The ending horizontal segment is from the filters on the floor. The middle section starts with a curve upward where the filters are accelerating. The middle section then is a straight line where the filters have reached terminal velocity and are no longer accelerating.



Note the following for students collecting the data in this way are:

- The graph goes up from left to right and does not look like it is the height-time graph of a falling object. This could be confusing to some students.
- The coffee filter can drift out of the beam of the CBR 2 as happened in the graph to the right. This may cause students to do repeated trials to get a good graph increasing the time for the activity.



2. Would the average speeds in the data table be the same? Why or why not?

   Student answers will vary.

   Sample response: The average speed (the absolute value of the velocity) would be the same. However, if the velocity is being recorded, this method gives positive velocities and the previous method (in the data table above) would give negative velocities.

3. Investigate further: acceleration due to gravity and terminal velocity.

   Student answers will vary.