Air Resistance – ID: 8739

Adapted from *Physics with Calculators* © 2006 Vernier Software and Technology

Time required
45 minutes

Topic: Force and Motion

- *Predict and describe the effect of balanced forces on an object.*
- *Describe the effect of friction on the motion of an object.*

Activity Overview

In this activity, students will collect data on the rate at which coffee filters fall. Students will attempt to determine the terminal velocity for different numbers of falling filters. They will then explore the relationship between mass and terminal velocity.

Materials

To complete this activity, each student or student group will require the following:

- *TI-Nspire™ technology*
- *five basket-style coffee filters*
- *copy of student worksheet*
- *pen or pencil*
- *Vernier CBR2™ or Go!™Motion sensor*
- *blank sheet of paper*

TI-Nspire Applications

Notes, Graphs & Geometry, Lists & Spreadsheet, Data & Statistics

Teacher Preparation

Students will probably be familiar with the idea that objects fall at different rates in air. Before beginning this activity, make sure students understand that these differences in falling rate are entirely due to the presence of air—some students may have the misconception that heavier objects fall more quickly than lighter objects.

- *The screenshots on pages 2–6 demonstrate expected student results. Refer to the screenshots on page 7 for a preview of the student TI-Nspire document (.tns file). Pages 8–10 show the student worksheet.*
- ***To download the .tns file and student worksheet, go to education.ti.com/exchange and enter "8739" in the search box.***

Classroom Management

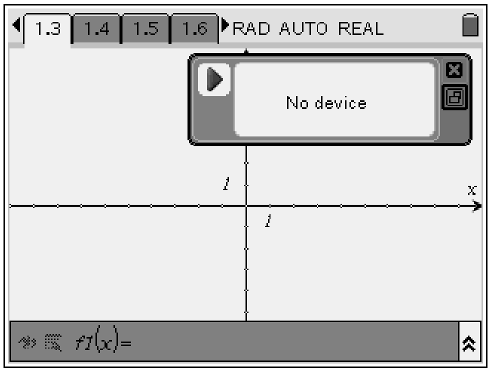
- *This activity is designed to be* ***student-centered****, with the teacher acting as a facilitator while students work cooperatively. The student worksheet guides students through the main steps of the activity and includes questions to guide their exploration. Students should record their answers to the questions on notebook paper.*
- *The ideas contained in the following pages are intended to provide a framework as to how the activity will progress. Suggestions are also provided to help ensure that the objectives for this activity are met.*
- *In some cases, these instructions are specific to those students using TI-Nspire handheld devices, but the activity can easily be done using TI-Nspire computer software.*

The following questions will guide student exploration during this activity:

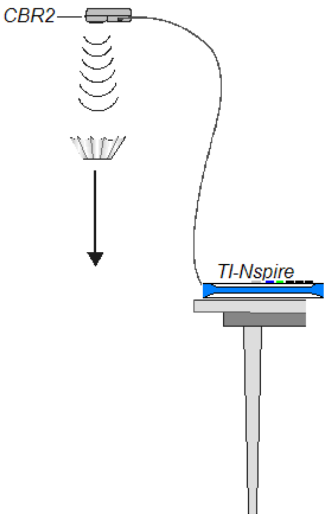
- How does the mass of an object affect its terminal velocity?
- What is the best mathematical model for the drag force?

Part 1: Collecting terminal velocity data

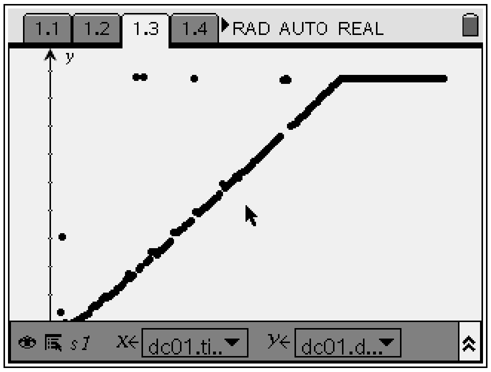
Step 1: First, students will use the Vernier CBR2™ or Go!™Motion sensor to collect data on the velocity of a falling coffee filter. Students should clamp or hold their motion sensors as high above the ground as possible; a distance of at least 2 m is ideal. They should then open the file **PhyAct_8739_air_resistance.tns** and read the first two pages. When students reach page 1.3, they should insert a new data collection box and then connect the motion sensor to the handheld. This should activate the motion sensor, and a distance display should appear in the data collection box.

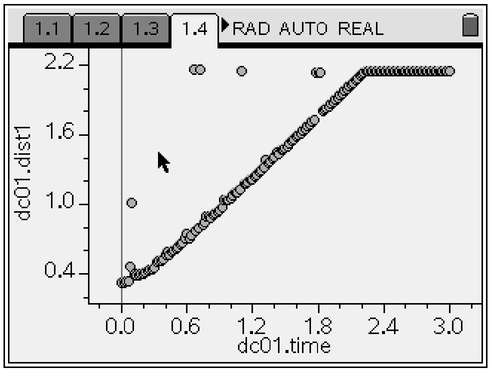


Step 2: One student from each group should now hold a single coffee filter below the wire mesh of the motion sensor, as shown to the right. The coffee filter should be no less than 0.4 m from the motion sensor. Students can use the distance display on the handheld to determine the distance from the sensor to the filter.



Step 3: Next, students will begin data collection and release the filters. If time allows, have students practice releasing the filters several times. They should be able to release the filters so that they fall straight down, with little sideways motion. Ideally, the students' motion graphs should resemble the one shown at right. Note: A small amount of noise in the data, as shown here, will not affect the results. The most important thing is that the graph have a significant region that is linear with a positive slope.

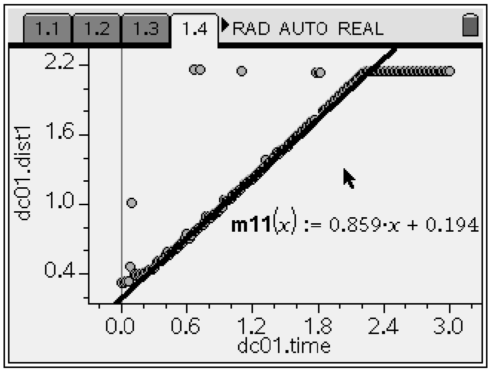




Step 4: After students have collected data, they will move to page 1.4, which contains a blank *Data & Statistics* application, and plot distance vs. time.

Q1. Describe the shape of the graph.

A. *The graph should have a short region of curvature, followed by a long linear region. The linear region represents the time during which the filter was falling at constant velocity.*



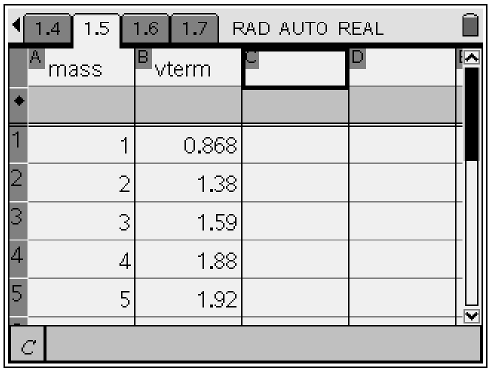
m11(x) := $0.859 \cdot x + 0.194$

Step 5: Next, students should attempt to fit a straight line to the linear portion of the graph. Students should use the **Movable Line** tool in the *Data & Statistics* application to produce the line that best fits their data. They should record the terminal velocity of the filter (the slope of the best-fit line) in the *Lists & Spreadsheet* application on page 1.5. Note: The TI-Nspire may automatically save data in the *Lists & Spreadsheet* application. If this occurs, students can delete the data by highlighting the columns and pressing clear. You may wish to have students record terminal velocities on a separate sheet of paper so they do not have to re-enter them if they are overwritten by collected data.

Q2. Why is using this **Movable Line** tool preferable to performing a linear regression in this case?

A. *The data set contains regions at the beginning and the end that are nonlinear. A linear regression would attempt to fit a line to the entire data set, not just the linear portion. As an extension activity, you could have students "trim" the nonlinear data from their data sets and then carry out a linear regression on the data. They can then compare the terminal velocities they determined using both methods and discuss any differences.*

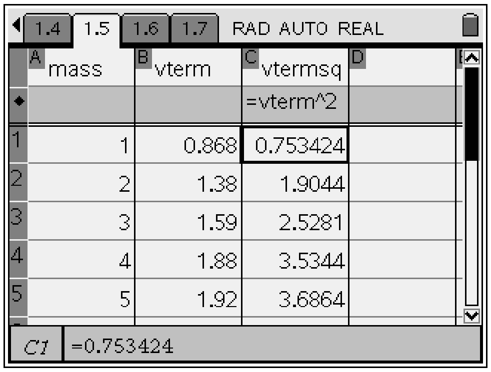
Step 6: Next, students repeat steps 2–5 using two, three, four, and five coffee filters. If time is short, you can have each group carry out the experiment with a different number of coffee filters, and then you can pool the data. Students should store their best-fit terminal velocities in the *Lists & Spreadsheet* application on page 1.5. Students may wish to add extra *Data & Statistics* applications instead of reusing the one on page 1.4. If students add extra pages, note that the page references on their instruction sheets may no longer be accurate.



	A mass	B vterm	C	D
◆				
1	1	0.868		
2	2	1.38		
3	3	1.59		
4	4	1.88		
5	5	1.92		

Part 2: Exploring the relationship between mass, drag force, and terminal velocity

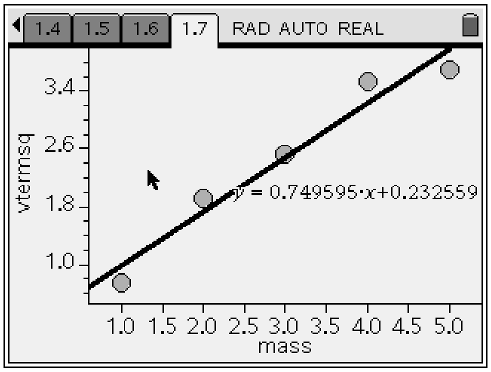
Step 1: First, students calculate the square of the terminal velocity for each of their trials in the *Lists & Spreadsheet* application on page 1.5.



	A mass	B vterm	C vtermsq	D
◆			=vterm^2	
1	1	0.868	0.753424	
2	2	1.38	1.9044	
3	3	1.59	2.5281	
4	4	1.88	3.5344	
5	5	1.92	3.6864	

C1 =0.753424

Step 2: Next, students move to pages 1.6 and 1.7, which contain empty *Data & Statistics* applications. Students plot **vterm** vs. **mass** on page 1.6 and **vtermsq** vs. **mass** on page 1.7. For each graph, students should change the **Window Settings** so that **XMin** and **YMin** are zero. They should then use the **Regression** tool to fit the data to a straight line.



Q3. Which proportionality ($m = kv_T$ or $m = kv_T^2$) best fits your data? That is, which graph (**vterm** vs. **mass** or **vtermsq** vs. **mass**) has data most consistent with a straight line that passes through the origin?

A. *The graph of* v_T^2 *vs. mass is closer to a direct relationship than is the graph of* v_T *vs. mass. In particular, the* v_T^2 *vs. mass graph passes close to the origin, while the* v_T *vs. mass graph does not. The data therefore suggest that, for these coffee filters, mass is proportional to* v_T^2*. Note that both data sets are very close to linear. Students may have difficulty determining which data set gives the best fit to the linear relationship. Remind them that, for this relationship, it is important that the best-fit line pass through the origin; this will help them differentiate between the two lines.*

Q4. Which of the drag force relationships (–*bv* or –*cv*^{2}) appears to model the data better?

A. *Since the v_T^2 vs. mass graph is closer to a direct proportionality, it appears that the drag force is proportional to the square of the velocity, or $F_{drag} = -cv^2$.*

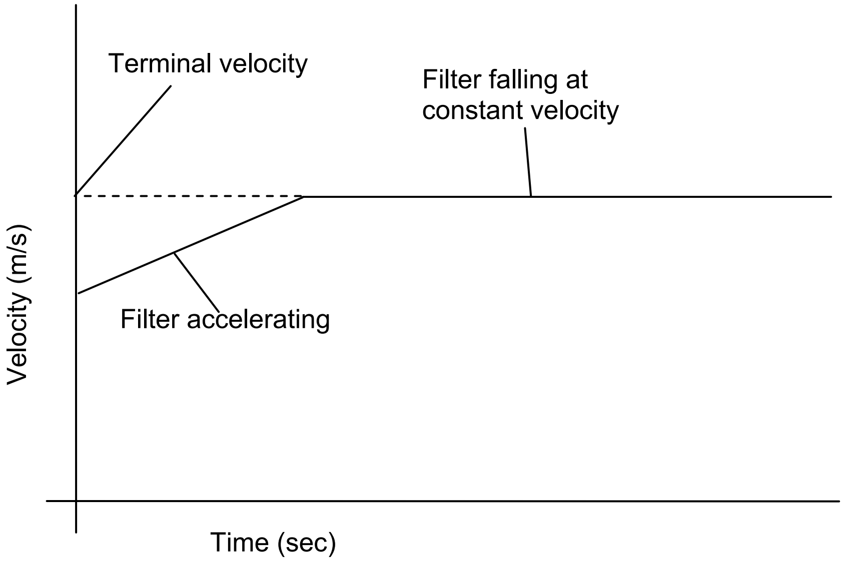
Q5. If one filter falls in time *t*, how long would it take four filters to fall, assuming the filters are always moving at terminal velocity?

A. *Since the graphs show that terminal velocity squared is directly proportional to mass, the terminal velocity of four filters is about twice as large as the terminal velocity of one filter. Therefore, if one filter falls in time* t*, four filters would fall in time 0.5*t*.*

Q6. Make a sketch of velocity vs. time for a falling coffee filter. On the graph, label the following:

- region(s) in which the filter is accelerating (if any)
- region(s) in which the filter is falling at constant velocity
- the terminal velocity of the filter

A.



Q7. Describe the forces acting on the filter in each region of the velocity vs. time sketch. Explain how these forces produce the motion you have drawn.

A. *At all times during the filter's fall, gravity is pulling it down, and air resistance (drag) is resisting its fall. During the time when the filter is accelerating, gravitational force is greater than drag force, so the net force on the filter is downward, and the filter accelerates. During the time when the filter is falling at constant velocity, gravitational force is equal to drag force. The net force on the filter is therefore zero, and the filter does not accelerate.*

Q8. Why does a coffee filter reach terminal velocity after falling less than 1 m, but a basketball or other heavier object must fall farther before reaching terminal velocity?

A. *Drag force is proportional to velocity (or velocity squared), so it increases as long as the falling object is accelerating. The object stops accelerating when the drag force equals the weight of the object. Therefore, a heavier object must fall a greater distance (a longer time) to reach a high enough velocity for the drag force to balance its weight.*

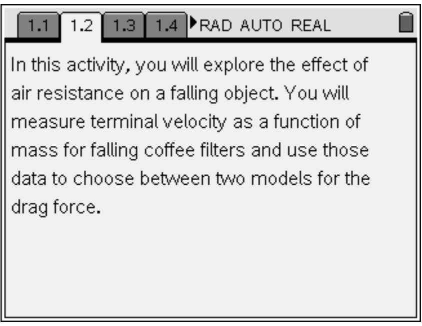
Air Resistance – ID: 8739

(Student)TI-Nspire File: *PhyAct_8739_air_resistance.tns*

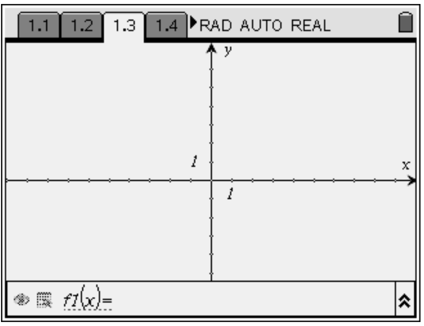
AIR RESISTANCE

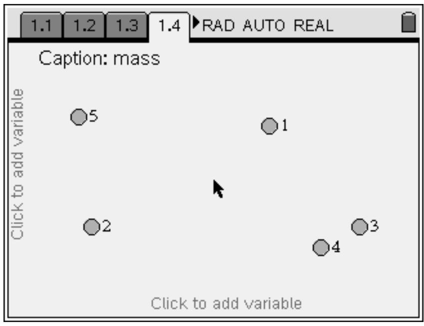
Physics

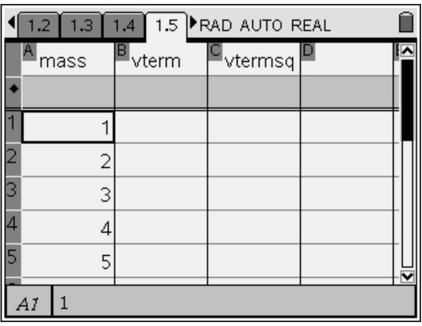
Drag Force



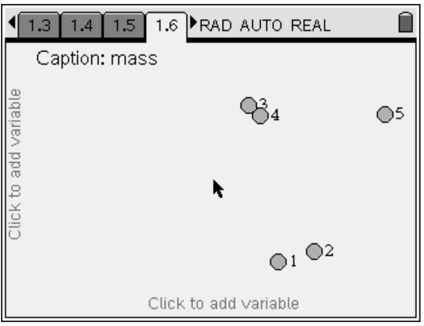
In this activity, you will explore the effect of air resistance on a falling object. You will measure terminal velocity as a function of mass for falling coffee filters and use those data to choose between two models for the drag force.

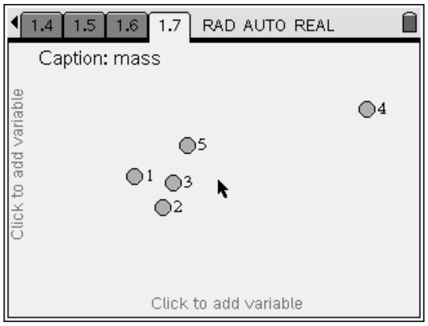






	A mass	B vterm	C vtermsq	D
◆				
1	1			
2	2			
3	3			
4	4			
5	5			





Air Resistance

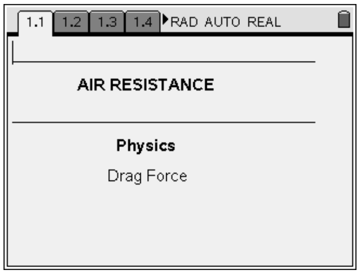
ID: 8739

Name ______________________

Class ______________________

In this activity, you will explore the following:

- *how the terminal velocity of a falling object is related to its mass*
- *the mathematical expression for the drag force*

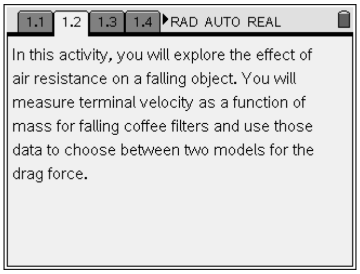


AIR RESISTANCE

Physics

Drag Force

Open the file **PhyAct_8739_air_resistance.tns** on your handheld or computer, and follow along with your teacher for the first two pages. Move to page 1.2 and wait for further instructions from your teacher.

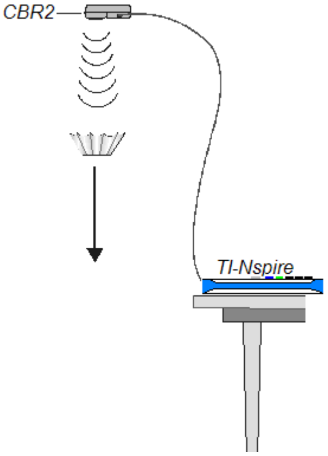


In this activity, you will explore the effect of air resistance on a falling object. You will measure terminal velocity as a function of mass for falling coffee filters and use those data to choose between two models for the drag force.

When you solve physics problems involving free fall, often you are told to ignore air resistance and to assume the acceleration is constant. In the real world, because of air resistance, objects do not fall indefinitely with constant acceleration. One way to see this is to compare the fall of a baseball and a sheet of paper when they are dropped from the same height. The paper will reach a constant speed quickly, but the baseball will still be accelerating when it hits the floor. Air has a much greater effect on the motion of the paper than it does on the motion of the baseball. The paper does not accelerate very long before air resistance reduces the acceleration so that it moves at an almost constant velocity. When an object is falling with a constant velocity, we describe it with the term “terminal velocity,” or v_T. The paper reaches terminal velocity very quickly, but on a short drop to the floor, the baseball does not.

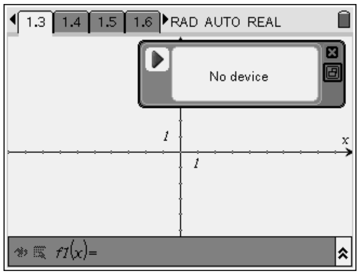
Air resistance is sometimes called drag force. Some experiments on falling objects have shown that the drag force is proportional to the velocity. Other experiments have shown that the drag force is proportional to the square of the velocity. In either case, the direction of the drag force is opposite to the direction of motion. In this experiment, you will measure terminal velocity as a function of mass for falling coffee filters, and then you will use the data to choose between the two models for the drag force. You will use coffee filters because they are light enough to reach terminal velocity in a short distance.

Part 1: Collecting terminal velocity data

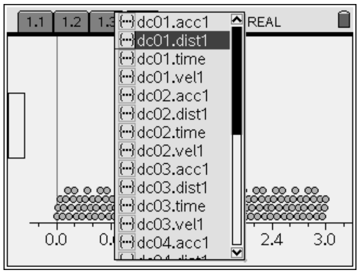


Step 1: Move to page 1.3. Support (or clamp) a Vernier CBR2™ or Go!™Motion sensor about 2 m above the floor, pointing down, as shown to the right. Insert a new data collection box on page 1.3 by pressing ctrl D. Connect the sensor to your handheld or computer. The light on the sensor should come on, and the display in the data collection box on the screen should show the current distance between the sensor and whatever object is below it. You will know the motion sensor is functioning correctly when you hear it make a soft, slow clicking sound.

Step 2: Place a coffee filter in the palm of your hand, and hold it about 0.5 m under the CBR2. Do not hold the filter closer than 0.4 m.

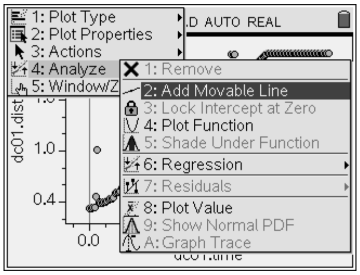


Step 3: Click the "play" button (►) to begin data collection. After the CBR2 begins clicking rapidly, release the coffee filter directly below the CBR2 so that it falls toward the floor. Move your hand out of the beam of the CBR2 as quickly as possible so that only the motion of the filter is recorded on the graph. View your distance graph. (To view your distance graph, press ctrl tab to switch to the *Graphs & Geometry* view. Change the plot type to scatter plot and plot distance vs. time. Adjust the window settings if necessary.) If the motion of the filter was too erratic to get a smooth graph, you will need to repeat the experiment. With practice, you will get the filter to fall almost straight down with little sideways motion.



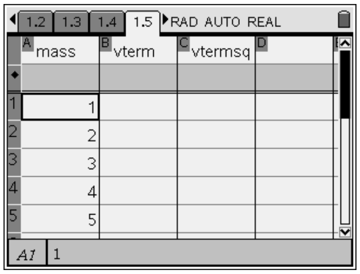
Step 4: When you have collected a clean data set, close the data collection box. You can then disconnect the motion sensor. Move to page 1.4, which contains a *Data & Statistics* application. Make a scatter plot of your data. Use the time data for the *x*-axis and the distance data for the *y*-axis.

Q1. Describe the shape of the graph.



Step 5: You can determine the velocity of the coffee filter from the slope of the distance vs. time graph. At the start of the graph, there should be a region of increasing slope (increasing velocity), and then the plot should become relatively linear. Since the slope of this line is velocity, the linear portion indicates that the filter was falling with a constant or terminal velocity (v_T) during that time. To fit a line to the linear region, add a **Movable Line** (**Menu** > **Analyze** > **Add Movable Line**) to the graph. This places a line over the data and allows you to translate and rotate the line to get a good fit. The resulting equation changes as you transform the line. Adjust the **Movable Line** so that it fits your data well. Record the terminal velocity of the single filter in Column B of the *Lists & Spreadsheet* application on page 1.5.

Q2. Why is using this **Movable Line** tool preferable to performing a linear regression in this case?



	A mass	B vterm	C vtermsq	D
◆				
1	1			
2	2			
3	3			
4	4			
5	5			

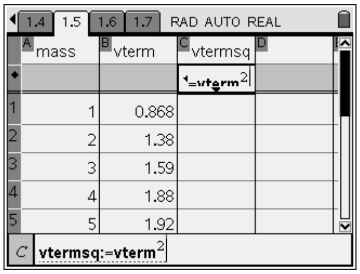
Step 6: Return to page 1.3, and restart the data collection by inserting a new data collection box and reconnect the motion sensor. Repeat steps 2–5 for two, three, four, and five coffee filters. Make sure to record each terminal velocity in the *Lists & Spreadsheet* application on page 1.5. In that spreadsheet, **mass** has units of coffee filters. (For the purposes of this activity, we will assume that all the coffee filters have the same mass.) If you wish, you can add extra *Data & Statistics* applications and use these extra applications to plot the data from your repeated trials.

Part 2: Exploring the relationship between mass, drag force, and terminal velocity

Mathematically, the drag force can be described using $F_{drag} = -bv$ or $F_{drag} = -cv^2$. The constants b and c are called the drag coefficients; they depend on the size and shape of the object. When the object is falling, there are two forces acting on it: the weight, mg, and air resistance, $-bv$ or $-cv^2$. At terminal velocity, the downward force is equal to the upward force, so $mg = -bv$ or $mg = -cv^2$, depending on the relationship between drag force and velocity. In either case, since g and b or c are constants, the terminal velocity is affected by the mass of the object. In other words, mass is directly proportional to either v_T or to v_T^2.

In this part of the activity, you will plot terminal velocity and terminal velocity squared against mass to try to learn which relationship—$m \propto v_T$ or $m \propto v_T^2$—correctly describes the falling coffee filters.

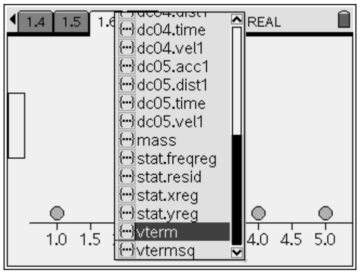
Step 1: First, you must calculate the square of the terminal velocity for each trial. Go to the *Lists & Spreadsheet* application on page 1.5. In the formula bar (light gray bar) in Column C, enter **=vterm²** and press enter. Column C should now be populated with the square of the terminal velocities in Column B.



	A mass	B vterm	C vtermsq	D
◆			=vterm²	
1	1	0.868		
2	2	1.38		
3	3	1.59		
4	4	1.88		
5	5	1.92		

C vtermsq:=vterm²

Step 2: Next, move to page 1.6, which contains an empty *Data & Statistics* application. Make a scatter plot of **vterm** vs. **mass**. Then, on page 1.7, make a scatter plot of **vtermsq** vs. **mass**. Change the **Window Settings** on each graph so that **XMin** and **YMin** are zero. Use the **Regression** tool to examine the linearity of each plot. Then, answer the questions below.



Q3. Which proportionality ($m = kv_T$ or $m = kv_T^2$) best fits your data? That is, which graph (**vterm** vs. **mass** or **vtermsq** vs. **mass**) has data most consistent with a straight line that passes through the origin?

Q4. Which of the drag force relationships ($-bv$ or $-cv^2$) appears to model the data better?

Q5. If one filter falls in time *t*, how long would it take four filters to fall, assuming the filters are always moving at terminal velocity?

Q6. Make a sketch of velocity vs. time for a falling coffee filter. On the graph, label the following:

- region(s) in which the filter is accelerating (if any)
- region(s) in which the filter is falling at constant velocity
- the terminal velocity of the filter

Q7. Describe the forces acting on the filter in each region of the velocity vs. time graph. Explain how these forces produce the motion you have drawn.

Q8. Why does a coffee filter reach terminal velocity after falling less than 1 m, but a basketball or other heavier object must fall farther before reaching terminal velocity?