



## PRELIMINARY QUESTIONS

1. Hold a single coffee filter in your hand. Release it and watch it fall to the ground. Next, nest two filters and release them. Did two filters fall faster, slower, or at the same rate as one filter? What kind of mathematical relationship do you predict will exist between the velocity of fall and the number of filters?
2. If there were no air resistance, how would the rate of fall of a coffee filter compare to the rate of fall of a baseball?
3. Sketch your prediction of a graph of the velocity vs. time for one falling coffee filter.
4. When the filter reaches terminal velocity, what is the net force acting upon it?

## PROCEDURE

1. Connect the Motion Detector.
  - a. Open the pivoting head of the Motion Detector.
  - b. If the Motion Detector has a sensitivity switch, set it to Normal.
  - c. Turn on the calculator. Connect the Motion Detector, data-collection interface, and calculator. (If you are using a direct-calculator cable, you do not need a data-collection interface.)
2. 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.
3. Support the Motion Detector about 2 m above the floor, pointing down, as shown in Figure 1.
4. Place a coffee filter in the palm of your hand and hold it about 0.5 m under the Motion Detector. Do not hold the filter closer than 0.15 m.
5. Select **[Start]** to begin data collection. Release the coffee filter directly below the Motion Detector so that it falls toward the floor. Move your hand out of the beam of the Motion Detector as quickly as possible so that only the motion of the filter is recorded on the graph.
6. View your distance graph.
  - a. When data collection is complete, a graph of distance vs. time will be displayed.
  - b. If the motion of the filter was too erratic to get a smooth graph, you will need to repeat the measurement. With practice, the filter will fall almost straight down with little sideways motion.
  - c. Repeat data collection as necessary. To do this, select **[Main]**, then **[Start]**, then **[OK]** to overwrite the latest data and begin data collection.

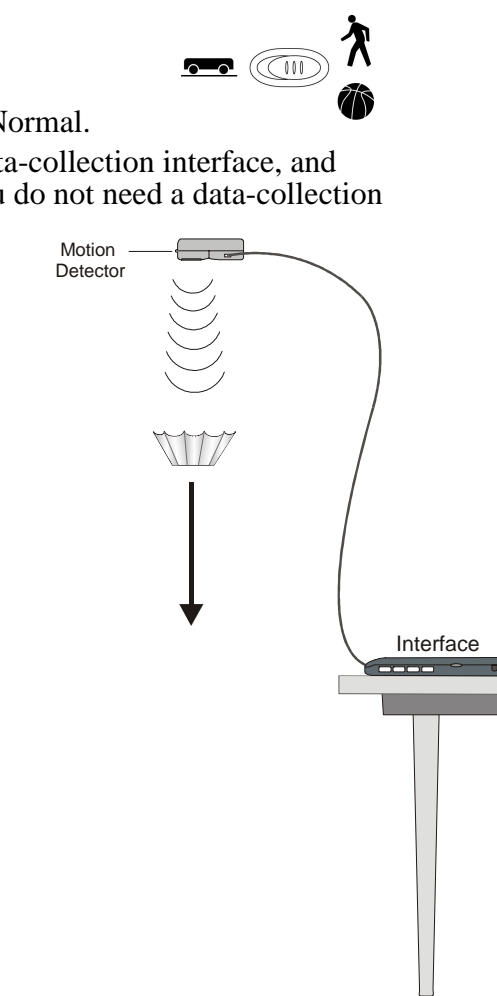


Figure 1

7. The velocity of the coffee filter can be determined 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 be 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, you first need to select that portion of your data.
  - a. Select **Anlyz**, then **Select Region...**, then **OK**.
  - b. Using the cursor keys, move the cursor to the left edge of the linear region corresponding to the filter in motion at constant speed and select **OK**.
  - c. Move the cursor to the right edge of the linear region, and select **OK**. You should now see only the linear region.
8. Fit a straight line to the region you just selected.
  - a. Select **Anlyz**, and then select **Linear Fit**.
  - b. Record the slope in the data table (a velocity in m/s).
  - c. Select **OK** to see the fit with your data, then select **Main** to return to the Main screen.
9. Repeat Steps 4–8 for two, three, four, and five coffee filters. (Optionally extend to six, seven and eight filters, but be sure to use sufficient fall distance so that a clear velocity can be measured.) **Note:** After selecting **Start**, select **OK** to overwrite the previous data and begin data collection.

## DATA TABLE

Number of filters	Terminal Velocity $v_T$ (m/s)	(Terminal Velocity) <sup>2</sup> $v_T^2$ (m <sup>2</sup> /s <sup>2</sup> )
1		
2		
3		
4		
5		

## ANALYSIS

1. To help choose between the two models for the drag force, plot terminal velocity  $v_T$  vs. number of filters (mass). On a separate graph, plot  $v_T^2$  vs. number of filters. Use your calculator, *Logger Pro*, or graph paper. Scale each axis from the origin (0,0).
2. During terminal velocity the drag force is equal to the weight ( $mg$ ) of the filter. If the drag force is proportional to velocity, then  $v_T \propto m$ . Or, if the drag force is proportional to the square of velocity, then  $v_T^2 \propto m$ . From your graphs, which proportionality is consistent with your data; that is, which graph is closer to a straight line that *goes through the origin*?
3. From the choice of proportionalities in the previous step, which of the drag force relationships ( $-bv$  or  $-cv^2$ ) appears to model the real data better? Notice that you are choosing between two different descriptions of air resistance—one or both may not correspond to what you observed.
4. How does the time of fall relate to the weight ( $mg$ ) of the coffee filters (drag force)? 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?

## EXTENSIONS

1. Make a small parachute and use the Motion Detector to analyze the air resistance and terminal velocity as the weight suspended from the chute increases.
2. Draw a free body diagram of a falling coffee filter. There are only two forces acting on the filter. Once the terminal velocity  $v_T$  has been reached, the acceleration is zero, so the net force,  $\Sigma F = ma = 0$ , must also be zero

$$\Sigma F = -mg + bv_T = 0 \quad \text{or} \quad \Sigma F = -mg + cv_T^2 = 0$$

depending on which drag force model you use. Given this, sketch plots for the terminal velocity ( $y$  axis) as a function of filter weight for each model ( $x$  axis). (Hint: Solve for  $v_T$  first.)

## TEACHER INFORMATION

## Air Resistance

1. The student pages with complete instructions for data collection using LabQuest App, Logger *Pro* (computers), EasyData or DataMate (calculators), and DataPro (Palm handhelds) can be found on the CD that accompanies this book. See *Appendix A* for more information.
2. Larger food-service size coffee filters of roughly the same proportions as consumer basket style coffee filters are available. Try to get some of these from a restaurant or your cafeteria. They make great demonstration devices.
3. There are numerous articles on the physics of air resistance. Two references from *The Physics Teacher* are “Modeling Air Drag,” by Christopher Brueningsen, et al., Volume 32, October 1994, page 439 ff, and “Effects of Air Resistance,” Vasilis Pagonis, et al., Volume 35, September 1997, page 364 ff.
4. Students need to recognize that during free fall the drag force is equal to the weight of the filters; therefore, the weight of the filters or number of filters equal drag force during terminal velocity. Best results are obtained by allowing the filters to fall a long distance. Consider having the students stand on a chair when releasing the filters. Release the filters from underneath, and don’t hold them from the side to avoid getting a reflection from the hand.
5. Motion detectors without a mode switch do not properly detect objects closer than 0.45 m. As a result such motion detectors must be farther away from the experiment than described in the student notes. In contrast, Motion detectors *with* a mode switch will detect objects as close as 0.15 m. Ideally an experiment will be set up so that the target is nearly this close at the point of closest approach, giving the best possible data.

## SAMPLE RESULTS

Number of filters	Terminal Velocity $v_T$ (m/s)	(Terminal Velocity) <sup>2</sup> $v_T^2$ (m <sup>2</sup> /s <sup>2</sup> )
1	xxxx	xxxx
2	xxxx	xxxx
3	xxxx	xxxx
4	xxxx	xxxx
5	xxxx	xxxx
6	xxxx	xxxx
7	xxxx	xxxx
8	xxxx	xxxx



Typical position vs. time graphs

## ANSWERS TO PRELIMINARY QUESTIONS

Answers have been removed from the online versions of Vernier curriculum material in order to prevent inappropriate student use. Graphs and data tables have also been obscured. Full answers and sample data are available in the print versions of these labs.

## ANSWERS TO ANALYSIS QUESTIONS

1. Two different models for the drag force:

