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

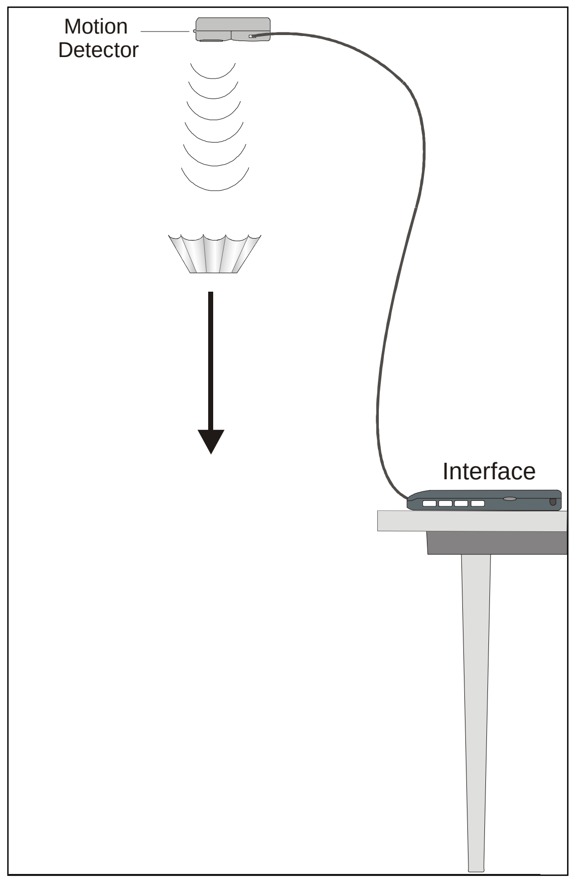

Figure 1

1. Support the Motion Detector about 2 m above the floor, pointing down, as shown in Figure 1.

2. Plug the Motion Detector into the DIG/SONIC 1 port of the LabPro interface. Connect the handheld to the LabPro using the interface cable. Firmly press in the cable ends.

3. Press the power button on the handheld to turn it on. To start Data Pro, tap the Data Pro icon on the Applications screen. Choose New from the Data Pro menu or tap (New) to reset the program.

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. Tap [Start] to begin data collection. After the interface beeps, 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. Examine your distance graph.

   a. 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.

   b. To collect data again, simply tap [Start] when you are ready to release the filter. Continue to repeat this process until you get a smooth graph.

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 become 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. Tap the Selection button, .
   b. Tap on the left boundary of the region of the distance *vs.* time graph that is linear. An arrow (>) is displayed on this line.
   c. Tap on the right boundary of the linear section. An arrow (<) is displayed on this line.
   d. Tap the Zoom button, , to display just the freefall portion of your data.

8. Fit a straight line to the region you just selected.
   a. Tap Analyze, then tap Curve Fit.
   b. Choose Linear as the Fit Equation.
   c. Record the slope in the data table (a velocity in m/s).
   d. Tap OK to view the fitted curve with your data.
   e. Tap OK once again to return to the Graph 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.)

DATA TABLE

Number of filters	Terminal Velocity v_T (m/s)	(Terminal Velocity)^2 v_T^2 (m^2/s^2)
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 handheld, Graphical Analysis, 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

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

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)^2 v_T^2 (m^2/s^2)
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: